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GEOPHYSICS

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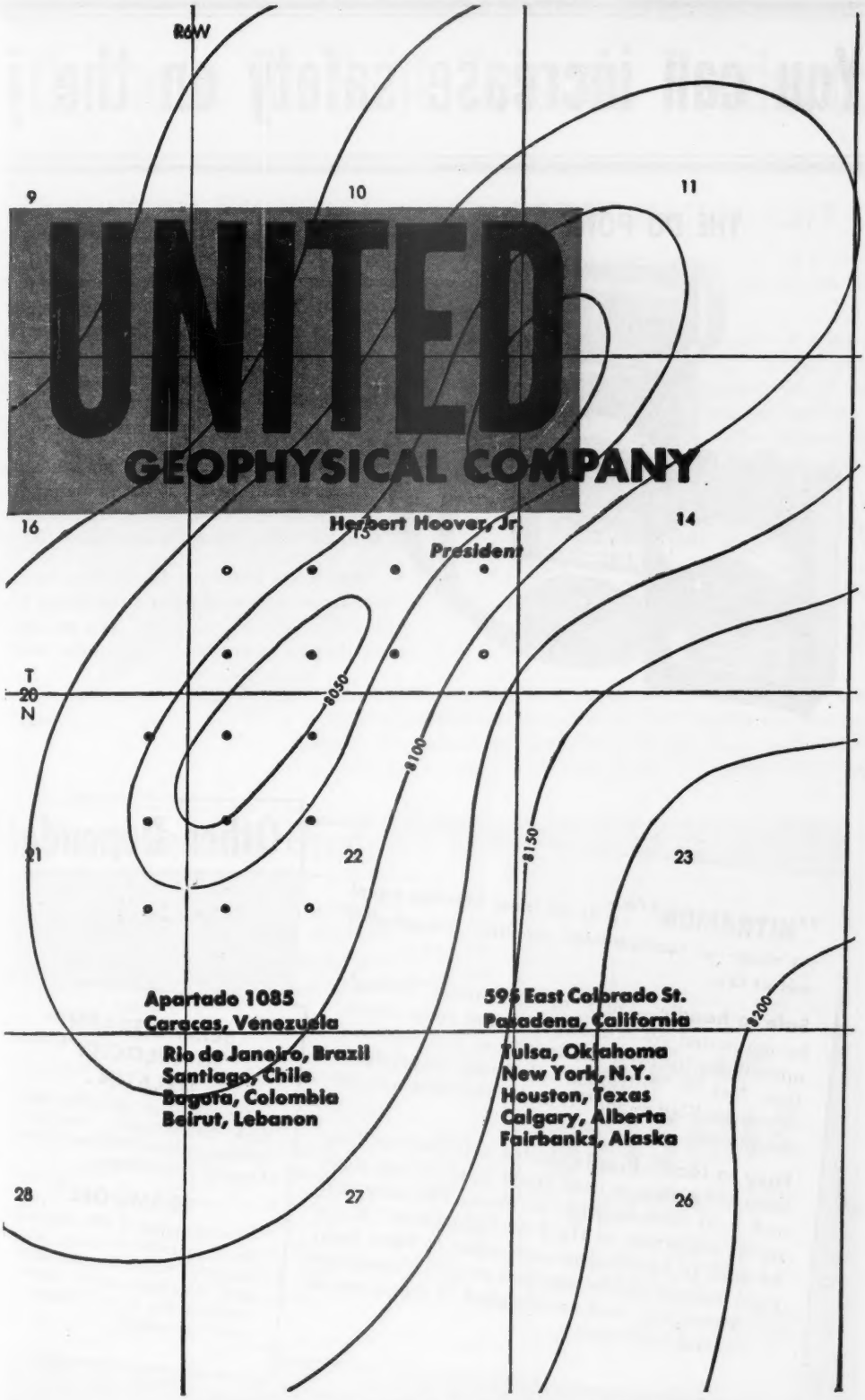

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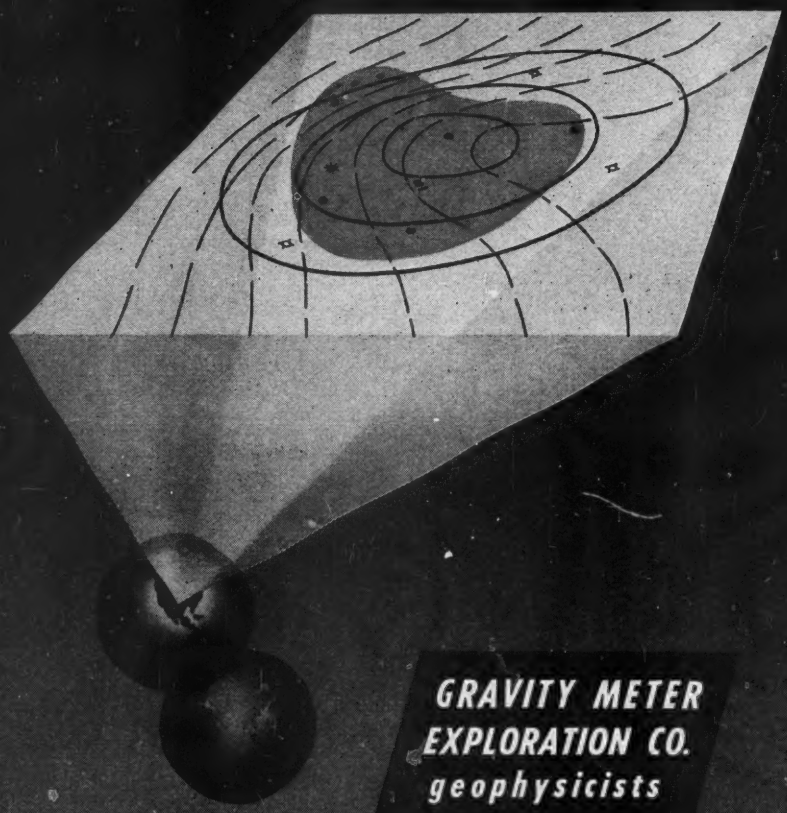

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GEOPHYSICS

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THE GRAVITY METER AS A GEODETIC INSTRUMENT*

GEORGE PRIOR WOOLLARD†

ABSTRACT

A special Worden temperature compensated gravity meter having a range of 5,500 mgals, and a reading sensitivity of 0.1 mgal was used to tie together various primary gravity base stations around the world and to establish new stations. Air transport was used and in a 3 month period over 80,000 miles were flown. Thirty-three pendulum stations were reoccupied involving a change in gravity of 3,800 mgals, and 125 gravity stations were established. The investigation demonstrated that this instrument could be used satisfactorily for long range geodetic work and the results appear to be the equal of good pendulum observations. Drift was corrected for on the basis of the drift rate established immediately before and after flights. Closures after correcting for drift averaged less than 0.4 mgals, and the closure for the world girdling loop was 0.33 mgals. The probable error based upon the gravity values at the reoccupied pendulum station was ± 0.5 mgals.

Reoccupation of the absolute gravity stations at the U. S. Bureau of Standards in Washington, D. C. and the National Physical Laboratory in Teddington, England, indicated an approximate 5 mgal error in these pendulum determinations. Indirect ties to the absolute gravity base in Potsdam, Germany, through the primary national gravity bases tied to it, indicated a 15 to 19 mgal error in the Potsdam absolute value. Most of the primary national gravity bases tied directly to Potsdam were found to agree among themselves to within 1 mgal, and the U. S. Bureau of Standards Absolute Base in Washington, D. C. to have a perfect connection within the limits of accuracy of the present measurements. This investigation was made under the auspices of the Office of Naval Research.

INTRODUCTION

The need for a better gravity meter may be said to have started with the formulation of the concept of gravity. It is also paradoxical that there was nearly a 100 years' lapse between the time that Sir Isaac Newton propounded the fundamental law of gravitational attraction and its experimental verification by Cavendish with a torsion balance.

The development of pendulum gravity apparatus was somewhat earlier, and was the direct outgrowth of Jean Richer's observation that a pendulum observatory clock which kept perfect time in Paris lost $2\frac{1}{2}$ minutes a day when taken to French Guiana. On the French Academy expeditions in 1735 to Lapland, and

* Presented at the St. Louis Meeting of the Society March 14, 1949. Manuscript received by the Editor, July 11, 1949.

† Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, and Dept. of Geology, University of Wisconsin, Madison, Wisconsin.

what is now Ecuador, to test the then controversial theory of polar flattening, Bouguer swung a crude pendulum at Quito and at the base of the Andes. This instrument was sufficiently accurate to indicate a deficiency of mass beneath the mountains.

The verification of polar flattening by the French Academy expeditions showing the need for restudying the shape of the earth, the appreciation of the significance of the departure of the vertical effects in laying out national boundaries by astronomic methods, and the phenomenon discovered by Bouguer in the Andes all aroused considerable interest in gravity measurements. Consequently, during the latter part of the last century numerous gravity observations were made in Europe, the United States and India. The instruments used for the most part were brass and bronze pendulums, and the measurements were mostly of a relative nature although absolute measurements were attempted in several countries.

The accuracy of these early observations was not very high as demonstrated by a repeat survey of some 50 odd older stations in Europe by the Isostatic Institute at Helsinki. An error of ± 18 mgals was indicated by this survey. The accuracy of later pendulum measurements increased appreciably because of improved pendulum instrumentation and better methods of timing and the accuracy of current geodetic pendulums is approximately ± 1 mgal. The highest degree of accuracy obtained with pendulum apparatus is believed to be about 0.1 mgal. This was obtained with the quartz pendulums developed by the Gulf Research and Development Co. Quartz pendulums also have been used by other groups such as Bullard and Browne at Cambridge University, England but with not such high precision.

The application of gravity observations to sub-surface exploration by the oil industry gave considerable impetus to the development of gravity instruments having high precision, portability and speed of operation. For the past 20 years gravity meters of various designs have been available which have an accuracy greater than 0.1 mgal and require only a few minutes for obtaining an observation. These instruments have not been suitable for geodetic work in that they were of limited range, subject to drift and had to be kept at constant temperature. Several instruments having low drift characteristics and high range have been built. However, the very serious handicap of maintaining constant temperature was not overcome until the development of the temperature compensated Worden Gravity Meter by the Houston Technical Laboratory in 1947.

At the request of the writer a trial model gravity meter for geodetic work was undertaken by the Houston Technical Laboratory to be used on long range gravity ties between existing pendulum stations in different parts of the world. That this instrument was a success will be shown by the results obtained.

ACKNOWLEDGEMENTS

The writer would like to acknowledge the cooperation, scientific interest and time and effort expended by Mr. Sam Worden of the Houston Technical Labora-

tory in building and developing the meter used on this investigation. To the Office of Naval Research, Geophysics Branch the writer is indebted for travel expenses and transportation on military aircraft on what appeared to be a gamble with poor chances of success. To the John Simon Guggenheim Foundation the writer is indebted for a fellowship covering the period of the investigation. For cooperation in the field both in making of measurements, hospitality and many other courtesies, the writer would like to express his appreciation to the many scientists at the gravity bases visited and to the officers and men of the United States Navy, Air Force and Army who directly assisted the writer both in this country and abroad.

DESCRIPTION OF THE WORDEN METER

The instrument supplied by the Houston Technical Laboratory was one of their standard exploration instruments. It was modified to include a high range reset spring which could be effectively read in conjunction with the normal reading spring throughout the entire range of both springs. The general specifications of the instrument are given in Table 1.

TABLE 1

GENERAL SPECIFICATIONS OF WORDEN GRAVITY METER

Range—5,500 mgals
Reading sensitivity—0.2 mgal and 0.01 mgal
Calibration accuracy—Tilt table calibration (1 part in 2,000)
Scale—linear
Lock—unclamped system
Temperature compensation—0.25 mgal/50°F. change in temperature
Drift—0.1 mgal/hr
Magnetic effects—nonmagnetic quartz system
Barometric effects—hermetically sealed in partial vacuum
Weight—approximately 5 lbs.
Size—over-all 5 inches×15 inches
Effect of bad jars and falls—a maximum of 2.2 mgals tare in reading
Effect of transit vibrations—negligible if properly shock mounted
Time of measurement—about 5 minutes
Auxiliary equipment—reading light battery mounted on case and tripod.
Total weight of equipment—20 lbs includes case, instrument and tripod

The principal of the instrument is essentially that of the Galitzan seismograph and a sketch of the meter is shown in Figure 1.

TESTING THE WORDEN METER

The instrument was tested under the auspices of the Geophysics Branch of the Office of Naval Research who supplied military plane transportation and travel funds. The itinerary is listed in Table 2.

U.S. Coast and Geodetic Survey pendulum bases were occupied in the Commerce Building, the Smithsonion Institution, the House Building and the Bureau of Standards in Washington, D.C., in San Francisco, California, in Honolulu, Hawaii and at Waianae in Oahu. Vening Meinesz pendulum stations were oc-

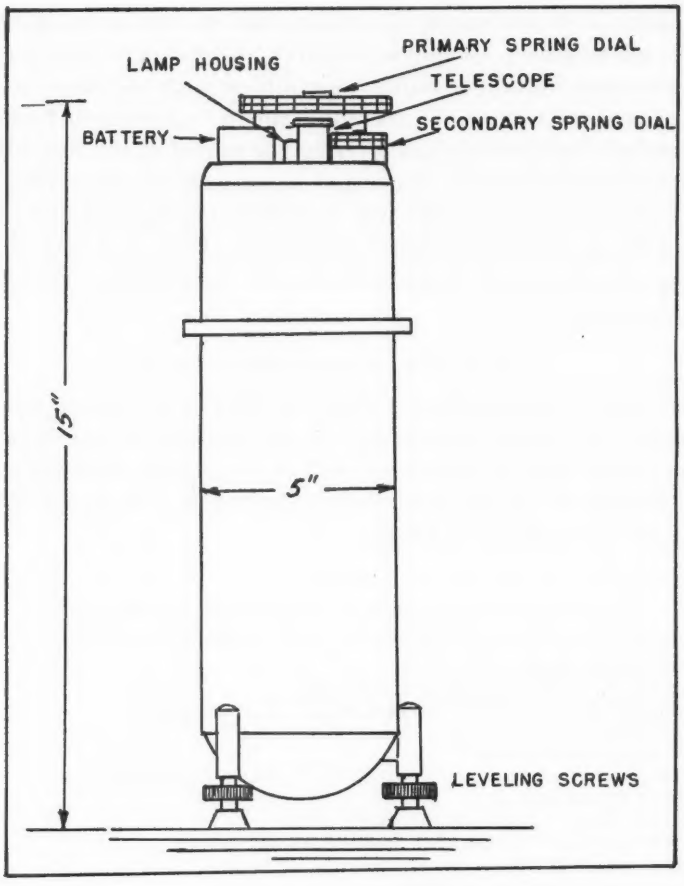

FIG. 1. Sketch of Worden Meter.

TABLE 2

ITINERARY FOLLOWED DURING INITIAL TESTS

July 21	Washington, D.C.—Westover, Massachusetts via Mitchell Field, Long Island—Westover, Massachusetts—Washington, D.C.—Patuxent, Maryland, U.S.A.
July 22	Patuxent, Maryland—Coco Solo, Panama, C.Z., via Norfolk and Jacksonville, Florida, U.S.A.
July 23	Coco Solo, Panama, C.Z.—Washington, D.C., U.S.A.
July 26	Washington, D.C., San Francisco, California via Fairfield—Suison AFB, U.S.A.
July 28	San Francisco, California—Washington, D.C., U.S.A.
July 29	Washington, D.C.—San Francisco, California, U.S.A.
July 31	San Francisco, California, U.S.A.—Oahu, Hawaii
Aug. 1	Oahu, Hawaii—Guam via Johnston Is., and Kwajalien
Aug. 3	Guam—Oahu, Hawaii
Aug. 7	Oahu, Hawaii—San Francisco, California, U.S.A.
Aug. 10	San Francisco, California—Washington, D.C., U.S.A.

cupied in Panama, C.Z., in San Franciso, California, in Honolulu, Hawaii, and in Guam. Because of the large discrepancy between the pendulum values reported for Panama by Ewing, and Hoskinson, and Vening Meinesz, and discrepancies between the U. S. Coast and Geodetic Survey values and those of Vening Meinesz in San Francisco, California and at Honolulu, Hawaii, no adequate field check on the calibration of the instrument could be secured. The manufacturer's calibration, however, appeared to agree on the whole with Vening Meinesz' values. The discrepancies between the various U.S. Coast and Geodetic Survey bases in the city of Washington reported by Hammer (1947) were substantiated by the measurements with the gravity meter.

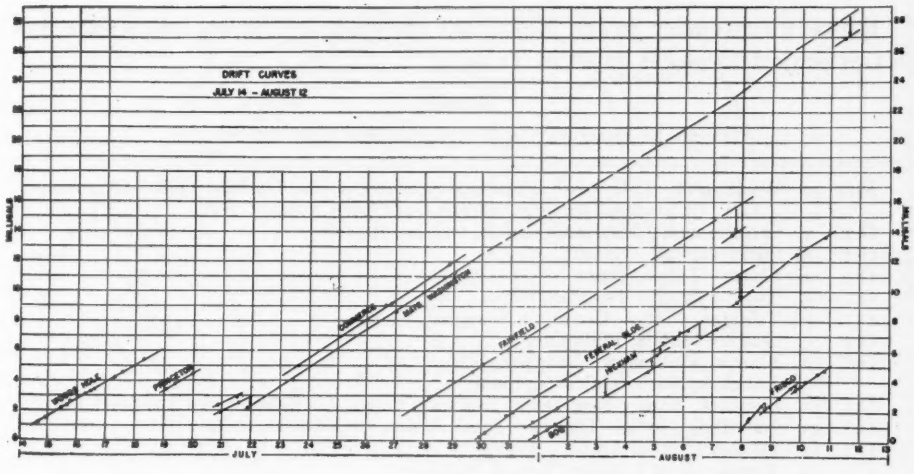

FIG. 2. Drift curves, July 14–August 12.

METHOD OF DRIFT CONTROL DURING TEST

Drift was determined by periodic measurements at a fixed base whenever possible and by using a drift rate established while on the ground between flights. In some instances this period for drift control was only of a few hours' duration. In all cases the mean of the drift rates established immediately before and after a flight was used for the flight period. The error in closure after correcting for drift was always small, averaging 0.3 mgal. It represented earth tide effects and effects of jars and handling of the instrument, as well as errors in drift estimation. In view of these small errors in closure even where periods of a week or more were involved, it was felt that for the purposes the instrument was to be used, drift could be satisfactorily accounted for by this method. The mean drift rate of the instrument for the period of the tests was about 0.06 mgal/hr and appeared to be very uniform as shown in Figure 2. The offsets in the drift curve were apparently caused by jars in transit and indicated the need for a better shock mounting on the carrying case.

GLOBAL GRAVITY MEASUREMENTS

In view of the satisfactory performance of the instrument on the tests conducted during July and August 1948, the Office of Naval Research contracted with the Woods Hole Oceanographic Institution to investigate gravity measurements on a global basis. The purpose of the measurements was:

(1) To check the accuracy of existing national pendulum bases around the world,
(2) To establish new gravity bases where none existed,
(3) To tie the present absolute gravity determination bases together so that their relative accuracy could be determined, and
(4) To establish an integrated network of stations whose relative values would be reliable, it was hoped, to better than 1 mgal.

Between September 30 and November 27, 1948 over 80,000 miles were flown on this project to places listed in Table 3.

TABLE 3

ITINERARY FOLLOWED IN MAKING GLOBAL GRAVITY SURVEY

Sept. 30	Washington, D.C.—San Francisco, California via Dayton, Ohio—Oklahoma City, Oklahoma, Denver, Colorado and Ogden, Utah, U.S.A.
Oct. 1	San Francisco, California, U.S.A.—Oahu, Hawaii
Oct. 3	Oahu, Hawaii—Guam
Oct. 4	Guam—Tokyo, Japan
Oct. 5	Tokyo, Japan—Tsingtao, China
Oct. 8	Tsingtao, China—Guam via Shanghai, China
Oct. 9	Guam—Manila, Phillipines
Oct. 10	Manila, Phillipines—Bangkok, Siam
	Bangkok, Siam—Calcutta, India
Oct. 11	Calcutta, India—New Delhi, India via Gaya, Allahabad and Cawnpore, India
Oct. 13	New Delhi, India—Dharhan, Saudi Arabia via Karachi, India
Oct. 14	Dhahran, Saudi Arabia—Tripoli
Oct. 18	Tripoli—Port Lyautey, French Morocco
	Port Lyautey, French Morocco—Azores
Oct. 19	Azores—Newfoundland
	Newfoundland—Westover, Massachusetts, U.S.A.
Oct. 20	Westover, Massachusetts, U.S.A.—Washington, D.C., U.S.A.
Oct. 26	Washington, D.C., U.S.A.—Westover, Massachusetts, U.S.A.
Oct. 28	Westover, Massachusetts, U.S.A.—Iceland via Goose Bay, Labrador
Oct. 29	Iceland—Lyneham, England and London, England
Nov. 1	London, England—Copenhagen, Denmark
Nov. 2	Copenhagen, Denmark—Helsinki, Finland via Stockholm, Sweden
Nov. 3	Helsinki, Finland—Stockholm, Sweden
Nov. 4	Stockholm, Sweden—Amsterdam and DeBilt, Holland
Nov. 5	Amsterdam, Holland—Paris, France
	Paris, France—London, England
Nov. 9	London, England—Port Lyautey, French Morocco via Bordeaux, France
Nov. 12	Port Lyautey, French Morocco—Tripoli
Nov. 13	Tripoli—Dhahran, Saudi Arabia via Khartoum, Anglo Egyptian Soudan
Nov. 14	Dhahran, Saudi Arabia—Ras Mushaab and return
	Dhahran, Saudi Arabia—Tripoli via Khartoum, Anglo Egyptian Soudan
Nov. 15	Tripoli—Frankfurt, Germany via Athens, Greece and Rome, Italy
Nov. 17	Wiesbaden, Germany—Marham, England and London, England
Nov. 20	Lyneham, England—Azores
Nov. 25	Azores—Newfoundland
	Newfoundland—Westover, Massachusetts, U.S.A.
Nov. 26	Westover, Massachusetts, U.S.A.—Ottawa, Canada
Nov. 27	Ottawa, Canada—Washington, D.C., U.S.A.

An over-all picture of the tracks followed on these trips and the earlier tests is shown in Figure 3. In additions to measurements on the above trips, observations were also made between Washington, D.C., and Woods Hole, Massachusetts, Washington, D.C., and Madison, Wisconsin, and Madison, Wisconsin and Houston, Texas.

The above observations constituted a better test of the gravity meter than the earlier ones because runs were made between points having more rigid pendulum

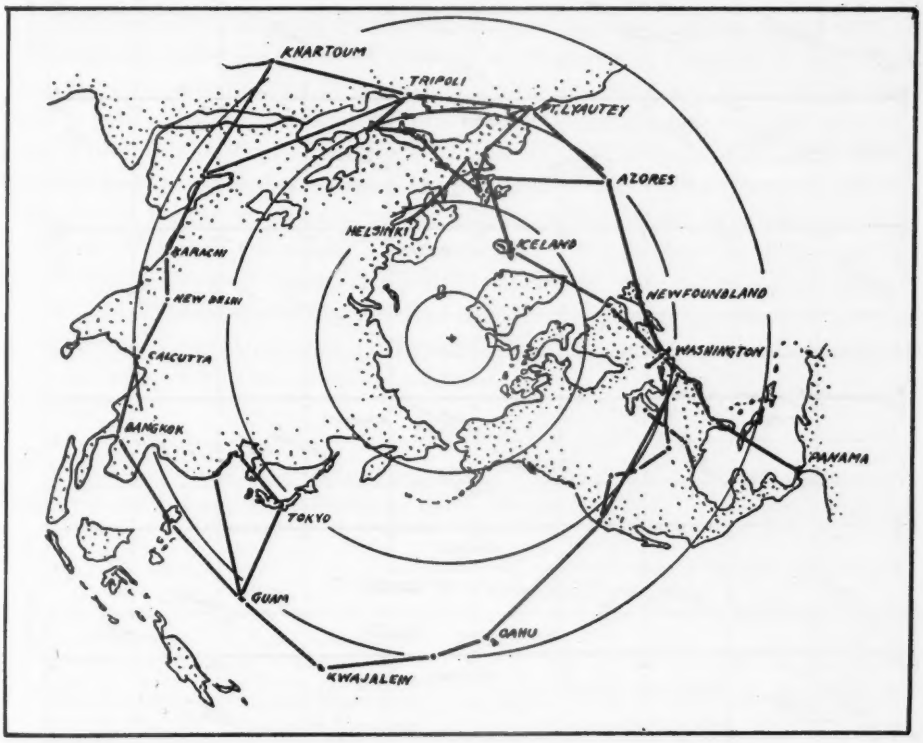

FIG. 3. World gravity tracks.

control, and involving a variation in gravity of more than 3,800 mgals. In addition, several sets of repeat measurements via the same and different tracks were made, and considerable differences in climatic conditions were encountered on some of the repeat measurements.

ACCURACY OF OBSERVATIONS

A record of sets of repeat measurements made at the same site showed that for 66 such sets of observations at different places the reading accuracy was 0.00 mgal, 0.03 mgal, and 0.07 mgal for the lower quartile, median value, and upper quartile respectively.

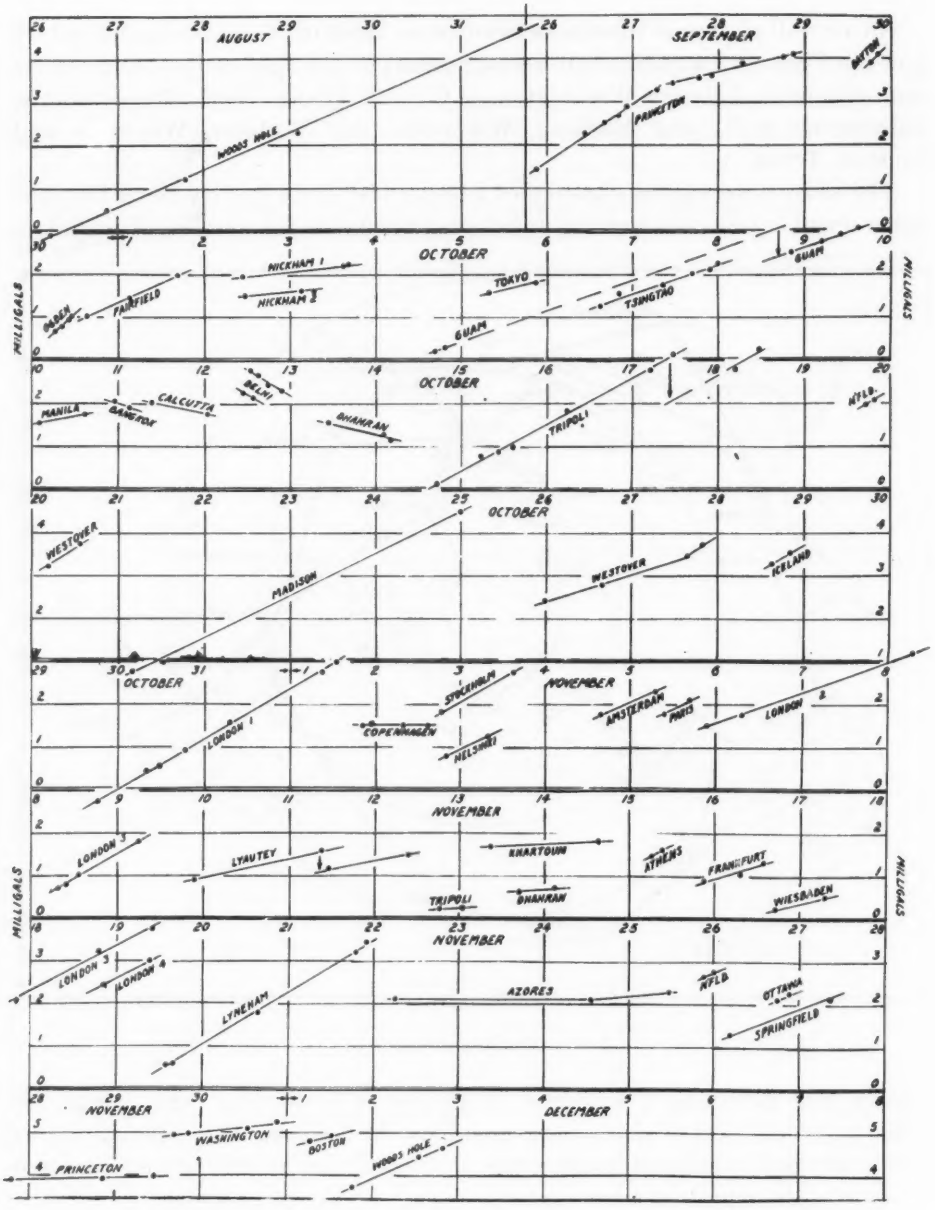

FIG. 4. Instrument drift, Worden Geodetic Gravimeter, world gravity measurements, 1948.

A somewhat more practial test is the accuracy with which the gravity interval between pairs of stations could be repeated. For 28 sets of such data values of 0.04 mgal, 0.08 mgal, and 0.13 mgal were obtained for the lower quartile, median value, and upper quartile respectively. Errors incorporated in the last group of data involve earth tide effects, inaccuracies in estimating drift, effects of rough handling, as well as the accuracy with which the instrument could be read.

DRIFT

The method of drift control was the same as employed on the earlier tests and the drift curves for the period of operations are shown in Figure 4. It will be seen that the drift rate was not as regular as on the first tests and a change in sign as well as rate also occurred. Despite this obvious difficulty it was found nessary to repeat only one portion of the work because of drift irregularities. That was the portion between Dhahran, Saudi Arabia and Tripoli. There was no obvious explanation for the capricious changes in drift rate observed, because, as a rule, it could be said that the colder the temperature, the higher the drift rate. The procedure of using the mean of the drift rates that were indicated immediately before and after a flight, for the period in flight, in general appeared to give very good results. This is indicated by the small errors in closure obtained on loops and the agreement with the 1st order pendulum data.

CLOSURES

As outlined under the section describing the results of the tests, closures represented the difference between the drift corrected results and original readings.

TABLE 4

CLOSURE ON MAJOR LOOPS

Washington, D.C., U.S.A.—Around world—Washington, D.C., U.S.A.	0.35 mgal
Guam—Tokyo, Japan—China—Guam	0.26 mgal
London, England—Helsinki, Finland—Paris, France—London, England	0.43 mgal
Tripoli—Khartoum, Egypt—Saudi Arabia—Tripoli	0.86 mgal
Washington, D.C.—Oklahoma City—San Francisco, California—Washington, D.C., U.S.A.	0.04 mgal
Washington, D.C., U.S.A.—Azores—England—Iceland—Washington, D.C., U.S.A.	0.51 mgal

Where there were known jars, a tare was established by repeated observations and allowance was made for such tares in establishing closure. Closures therefore represent all unknown factors including earth tide effects. Loops on which closure was established are indicated graphically in Figure 5. The average closure for 6 major loops covering 2,000 or more mgals with an average period of 10 days was 0.33 mgal. The detailed values are given in Table 4.

Closure on lesser loops completed in one or two days was of the same order of magnitude having an average closure of 0.35 mgal.

FINAL ADJUSTED VALUES

In determining the final values to be used, the Washington, D.C., U.S.A., Commerce building base was used as datum and the closure of the world girdling loop (0.35 mgal) was distributed on the basis of the number of stations occupied. Stations in Europe were adjusted for closures on the National Physical Laboratory at Teddington, England. The Teddington value was based on the mean value determined over four different routes from Washington, D.C., U.S.A. These were (1) via Iceland, (2) via the Azores, (3) via Port Lyautey, French Morocco and Bordeaux, France and (4) via Tripoli, Athens, Greece and Frank-

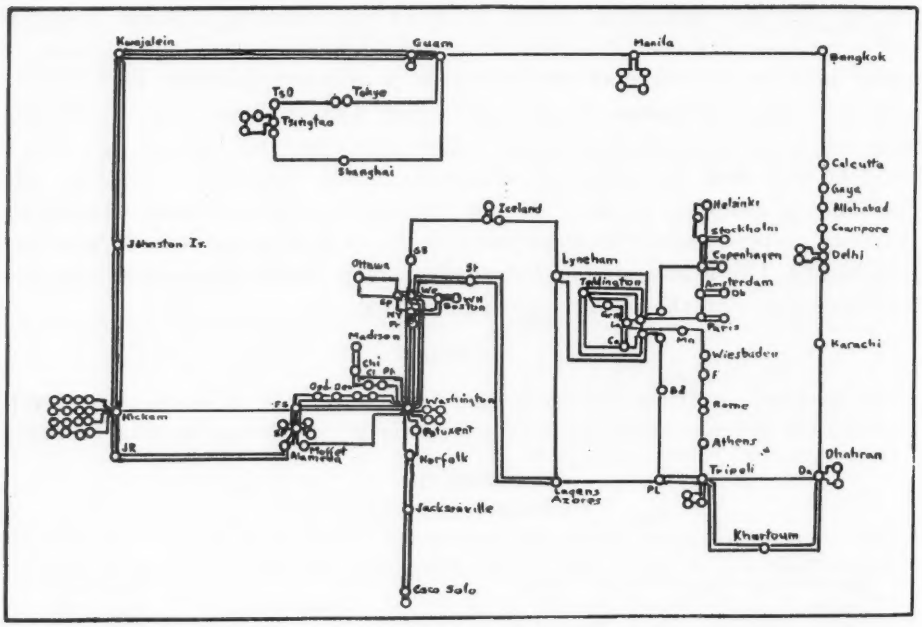

FIG. 5. World gravity circuits, 1948.

furt, Germany. The average deviation from the mean for the interval between Washington, D.C., U.S.A. and Teddington, England via these four routes was 0.24 mgal.

CALIBRATION

The calibration supplied by the manufacturer was 0.9953 and was a tilt table calibration. This method of calibration is not regarded as accurate to better than 1 part in 2,000 at best, and in view of the large change in gravity measured by these measurements, i.e., 4,000 mgals, an effort was made to occupy as many pendulum stations as possible to effect a field calibration.

Tilt table calibration: The fundamental relation involved in the tilt table calibration is as follows:

$$\cos\theta = G - \Delta G/G$$

where θ is the angle of tilt, G is the force of gravitational attraction at the point of observation, and ΔG the effective change in gravity for θ.

In carrying out the calibration by this method, Johanasson blocks with a tolerance of ± 0.000005 inch are used to raise one end of the table, and readings of the meter are taken for different values of θ with corresponding values of ΔG. The instrument used was calibrated for ΔG increments of 320, 500, 12,492 and 15,695 gravity units. A spread in the calibration constant from 0.9940 to 0.9966 was obtained which bracketed the field calibration value of 0.995 based upon the reoccupation of pendulum stations. This spread in the tilt table calibration values appears to be related to a non-uniform pitch of the thread of the screw of the

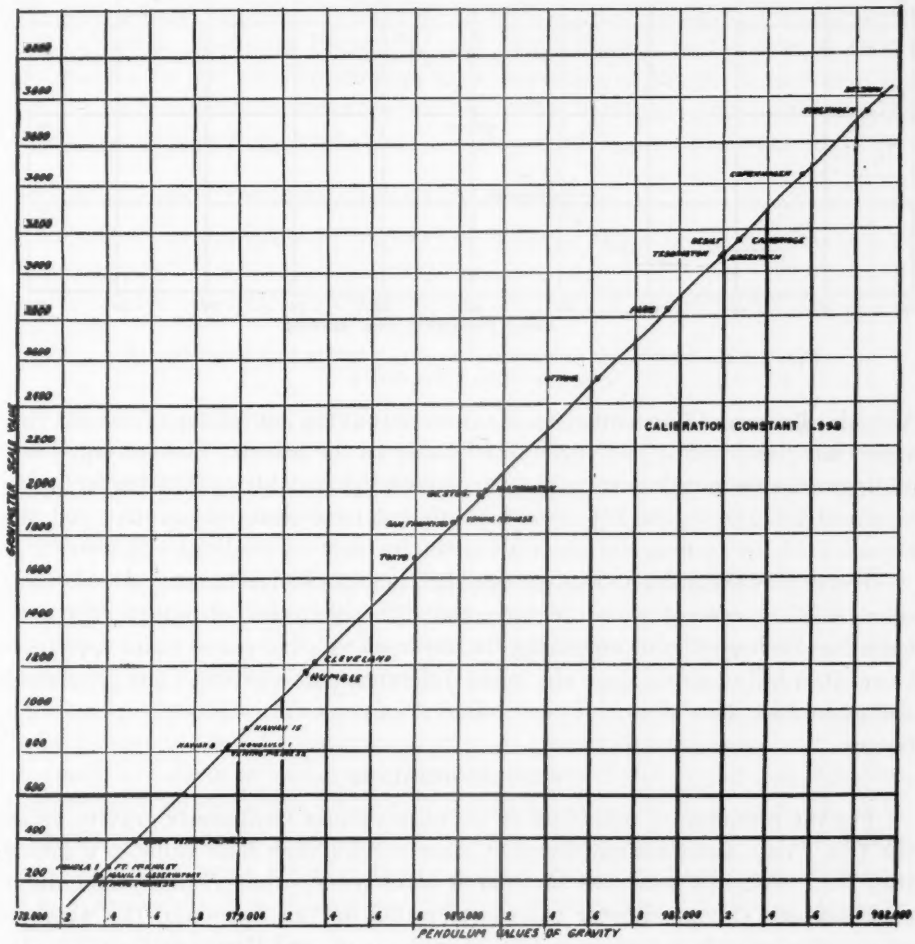

FIG. 6. Calibration curve, Worden Geodetic Gravimeter, based on reoccupation of pendulum stations.

primary dial. The effect is also discernible in the conversion factor relating the primary and secondary spring dials of the instrument. Since the full range of the secondary dial (5 revolutions) equals only 6/100 revolution of the primary dial, the magnitude of the effect can only be established over a large change in gravity. The effect was not recognized on early tests for variations in the conversion constant between the two spring dials as by chance the points used gave values that agreed within the limits of accuracy of reading the instrument. However, more detailed tests conducted during the summer of 1949 between San

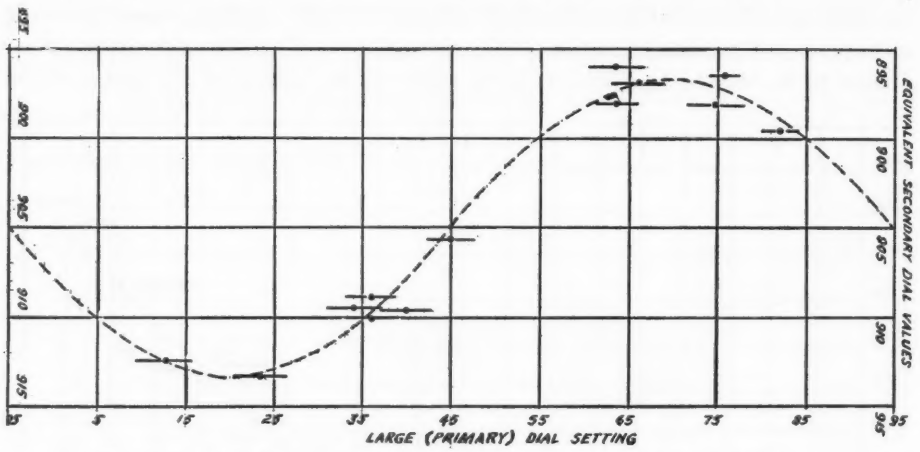

FIG. 7. Relation between primary and secondary spring dials on gravimeter.

Antonio, Texas and Fairbanks, Alaska showed that the conversion factor did vary appreciably and bore a sine curve relationship to the primary dial setting. These findings are shown in Figure 7. They explained the variable calibration factor determined in 1948 on the tilt table for different increments of gravity, and also necessitated the recomputation of all of the instrument readings and results.

The new field calibration value based on these revised data is 0.992 which is in substantial agreement with the corrected tilt table value of 0.9922. The later value has been used in recomputing the observed value of gravity and appears to be substantially correct since the mean difference curve between the gravimeter and pendulum data shows no perceptible slope over approximately 4,000 mgals range.

RESULTS OBTAINED

For the preliminary reduction of the observations to absolute gravity values the U.S. Coast and Geodetic Survey Commerce Building Base value in Washington, D.C. (980.118 gals) was adopted as a reference value. A plot of the difference between the gravimeter values computed on this basis and the weighted mean adjusted values determined by Morelli (1946) and Hirvonen (1948) for the

primary national gravity bases occupied indicated that the Commerce Building base value was 1 mgal low relative to the mean difference curve giving the best fit for all the pendulum data. The Commerce Building base value has therefore been raised to 980.119 gals in determing the absolute gravity values.

In presenting the results, the data are divided into three groups. Group 1 consists of values obtained at the primary national gravity bases occupied. Group 2 consists of values obtained at other pendulum bases. Group 3 consists of new determinations.

Group 1, Ties to Primary Gravity Bases:

For comparative purposes the gravity meter values are listed in Table 5 together with the pendulum data for all pendulum stations occupied at which 3 or more sets of observations are available. In addition, the weighted mean adjusted values (Morelli, 1946 and Hirvonen, 1948) are included. In the case of Dehra Dun, India a tie was affected through the cooperation of Mr. B. L. Gulattee, Director of the Geodetic & Research Section of the Survey of India who tied the writer's base at New Delhi, India to Dehra Dun, India using a Frost gravity meter.

Group 2, Secondary Pendulum Stations Occupied.

In Table 6 are presented comparative data for those pendulum stations at which there were fewer check observations.

The data for Group 3, new observations, are given in Appendix A at the end of the paper.

PROBABLE ERROR

If the accuracy of the gravimeter data is evaluated on the basis of all the pendulum stations occupied, i.e., the data of Table 5 and Table 6, with allowance made for known errors in pendulum data, the gravimeter error distribution would be 0.2 mgal, 0.9 mgal, and 1.7 mgals for the lower quartile, median value, and upper quartile, respectively.

If only the primary stations, i.e., Table 5, are used, with allowance made for the known errors at Cambridge, England, and Washington, D.C., U.S.A., the error distribution is 0.2 mgal, 0.5 mgal and 0.8 mgal for the lower quartile, median value, and upper quartile, respectively.

Figure 8 illustrates the comparative results for all pendulum stations occupied using the mean of the adjustments at national bases (Morelli, 1946, and Hirvonen, 1948), the mean of values at other stations where the spread was less than 10 mgals, and single values where the spread was greater than 10 mgals as in Panama, C.Z. and Manila, Philippines, or where only single values are available. Where there are known errors in the pendulum data as at Cambridge, England and in Washington, D.C., U.S.A. as indicated by the data of Table 5, the base values have been corrected.

TABLE 5

COMPARATIVE GRAVITY VALUES AT PRIMARY PENDULUM BASES OCCUPIED RELATIVE TO WASHINGTON, D.C., U.S.A., COMMERCE BLDG. BASE (980.119 GALS.)

Copenhagen, Denmark		
	Pendulum Data (Hirvonen, 1948)	
1930	Schmehl from Potsdam, Germany	981.5556
1930	Andersen from Potsdam, Germany	.5621
1935	Andersen from Potsdam, Germany	.5606
1935	Brockamp from Potsdam, Germany	.5577
	Adjusted Values	
1946	Morelli (original)	.5584
1948	Morelli (corrected by Hirvonen)	.5586
1948	Hirvonen	.5575
	Gravity Meter Data	
1933	Nörlund and Schneider from Stockholm, Sweden	.5612
1948	Woollard from Washington, D.C., U.S.A.	.5569
Stockholm, Sweden		
	Pendulum Data (Hirvonen, 1948)	
1926	Peasonen from Helsinki, Finland	981.8472
1930	Schmehl from Potsdam, Germany	.8462
1930	Andersen from Potsdam, Germany	.8473
1941	Wideland from Helsinki, Finland	.8488
	Adjusted Values	
1946	Morelli (original)	.8466
1948	Morelli (corrected by Hirvonen)	.8468
1948	Hirvonen	.8475
	Gravity Meter Data	
1933	Nörlund and Schneider from Copenhagen, Denmark	.8454
1948	Woollard from Washington, D.C., U.S.A.	.8476
Helsinki, Finland		
	Pendulum Data (Hirvonen, 1948)	
1926	Pesonen from Stockholm, Sweden	981.9148
1930	Schmehl from Potsdam, Germany	.9149
1930	Andersen from Potsdam, Germany	.9189
1935	Hirvonen from Potsdam, Germany	.9159
1941	Wideland from Stockholm, Sweden	.9150
	Adjusted Values	
1946	Morelli (original)	.9164
1948	Morelli (corrected by Hirvonen)	.9158
1948	Hirvonen	.9158
	Gravity Meter Data	
1933	Nörlund and Schneider from Copenhagen, Denmark	.9157
1948	Woollard from Washington, D.C., U.S.A.	.9161
DeBilt, Holland		
	Pendulum Data (Hirvonen, 1948)	
1921	Vening Meinesz from Potsdam, Germany	981.2670
1925	Vening Meinesz from Potsdam, Germany	.2690
1934	Holweck from Binningen, Holland	.2663
	Adjusted Values	
1946	Morelli (original)	.2680
1948	Morelli (corrected by Hirvonen)	.2680
1948	Hirvonen	.2679
	Gravity Meter Value	
1948	Woollard from Washington, D.C., U.S.A.	.2688
Paris, France		
	Pendulum Data (Hirvonen, 1948)	
1900	Putnam from Potsdam, Germany	980.942
1900	Haid from Karlsruhe, Germany	.933
1926	Vening Meinesz from DeBilt, Holland	.9428
1932	Holweck from Binningen, Holland	.9466
1933	Nörlund from Potsdam, Germany	.9439
1933	Nörlund from Binningen, Holland	.9450

TABLE 5—(*continued*)

1934	Holweck from DeBilt, Holland	.9456
1934	Holweck from Binningen, Holland	.9438
1935	LeJay from Potsdam, Germany	.9431
1935	LeJay from Benningen, Holland	.9406
	Adjusted Values	
1946	Morelli (original)	.9461
1948	Morelli (corrected by Hirvonen)	.9454
1948	Hirvonen	.9435
	Gravity Meter Values	
1948	Woollard from Washington, D.C., U.S.A.	.9439
Rome, Italy		
	Pendulum Data (Hirvonen, 1948)	
1893	Lorenzoni from Padua, Italy	980.351
1894	v. Triulzi from Padua, Italy	.335
1894	v. Triulzi from Vienna, M.G.I.	.348
1897	Baglione from Padua, Italy	.344
1912	Reina from Potsdam, Germany	.367
1923	Cassinis from Padua, Italy	.364
1932	Holweck from Paris, France	.366
1932	Holweck from Binningen, Holland	.370
	Adjusted Values	
1946	Morelli (original)	.3663
1948	Morelli (corrected by Hirvonen)	.3659
1948	Hirvonen	.3663
	Gravity Meter Value	
	1948 Woollard from Washington, D.C., U.S.A.	.3631*
Greenwich, England		
	Pendulum Data (Hirvonen, 1948)	
1892	Defforges from Paris, France	981.199
1893	v. Sterneck from Vienna, M.G.I.	.184
1900	v. Sterneck from Potsdam, Germany	.188
1900	Putnam from Potsdam, Germany	.188
1900	Putnam from Paris, France	.190
1928	Miller from Potsdam, Germany	.189
1931	Bullard from Paris, France	.1852
	Adjusted Value	
1946	Morelli (original)	.1893
1948	Morelli (corrected by Hirvonen)	.1884
1948	Hirvonen	.1880
	Gravity Meter Values	
1948	Woollard from Washington, D.C., U.S.A.	.1914
Tokyo, Japan		
	Pendulum Data (Hirvonen, 1948)	
1900	Borrass from Potsdam, Germany	979.799
1904	Hecker from Potsdam, Germany	.801
1906	Alessio from Padua, Italy	.798
	Adjusted Values	
1946	Morelli (original)	.801
1948	Hirvonen	.799
	Gravity Meter Value	
1948	Woollard from Washington, D.C., U.S.A.	.7993
New Jersey Ave Base, Washington, D.C., U.S.A.		
	Pendulum Data (Duerksen)[1]	
1893	Defforges from Paris, France	980.112
1900	Putnam from Potsdam, Germany	.113
1928	Vening Meinesz from DeBilt, Holland	.120
1929	Brown and Lushene from Commerce Base, Washington, D.C., U.S.A.	.1183
1929	Miller from Potsdam, Germany	.1184
1947	Brown and Hoskinson from Commerce Base, Washington, D.C., U.S.A.	.1161
	Adjusted Values	

[1] Personal communication.
* Exact site not recovered.

TABLE 5—(*continued*)

1946	Morelli (original)	.1180
1948	Morelli (corrected by Hirvonen)	.1184
1948	Hirvonen	.1191
	Gravity Meter Values	
1946	Hammer from Commerce Base, Washington, D.C., U.S.A.	.1146
1947	Drake from Commerce Base, Washington, D.C., U.S.A.	.1148
1948	Woollard from Commerce Base, Washington, D.C., U.S.A.	.1145
1949	Shelton from Commerce Base, Washington, D.C., U.S.A.	.1145
Ottawa, Canada		
	Pendulum Data (Hirvonen, 1948)	
1914	McDiarmid from Washington, D.C., U.S.A.	980.622
1921	Miller from Washington, D.C., U.S.A.	.625
1928	Miller from Potsdam, Germany	.622
1929	Miller from Washington, D.C., U.S.A.	.622
	Adjusted Values	
1946	Morelli (original)	.6210
1948	Morelli (corrected by Hirvonen)	.6219
1948	Hirvonen	.6225
	Gravity Meter Value	
1948	Woollard from Washington, D.C., U.S.A.	.6213
Dehra Dun, India		
	Pendulum Data (Gulatee, 1948)	
1904	Lenox-Conyngham from Kew, England	979.063
1901	Alessio from Potsdam via Colaba	.059
1905	Hecker from Potsdam via Jalpaiquri	.065
1913	Alessio from Genoa, Italy	.079
1924	Cowie from Kew	.054
1927	Glennie from Cambridge, England	.072
1929	Glennie and Cowie from Kew	.068
1929	Spoleto from Genoa, Italy	.069
1929	Vening Meinesz from DeBilt, Holland via Colombo	.075
1932	LeJay from Potsdam via Colombo	.085
1939	Browne and Glennie from Cambridge, England	.056
	Adjusted Value	
1946	Morelli (original)	979.073
1948	Hirvonen	.081
	Gravity Meter Value	
1948	Woollard and Gulatee from Washington, D.C., U.S.A., via Delhi	.064
Cambridge, England (Pendulum House)		
	Pendulum data (Bullard and Joly, 1936)	
1925	Vening Meinesz from DeBilt, Holland	981.265
1926	Lenox-Conyngham and Manly from Kew, England	.265
1930	Joly and Willis from Greenwich, England	.2630
1932	Bullard from Edinburgh, Scotland	.2645
	Adjusted Value	
1936	Bullard	.2645
	Gravity Meter Values	
1947	Anglo Iranian Oil Co. from Teddington, England	.2681
1948	Woollard from Washington, D.C., U.S.A.	.2689
1948	Browne from Teddington, England	.2678
Bureau of Standards (Absolute Base) Washington, D.C., U.S.A.		
	Pendulum Data (Brown, 1936)	
1933	Brown from Potsdam, Germany	980.1000
	Gravity Meter Values	
1936	Hammer from Commerce Base, Washington, D.C., U.S.A.	.0995
1948	Woollard from Commerce Base, Washington, D.C., U.S.A.	.0998
1949	Worzel from Commerce Base, Washington, D.C., U.S.A.	.0995
Smithsonian Institution Washington, D.C., U.S.A.		
	Pendulum data from Duerksen	
1932	Lushene from Commerce Base, Washington, D.C., U.S.A.	980.1209
1947	Hoskinson from Commerce Base, Washington, D.C., U.S.A.	.1193
	Gravity Meter Values	
1948	Woollard from Commerce Base, Washington, D.C., U.S.A.	.1179
1949	Shelton from Commerce Base, Washington, D.C., U.S.A.	.1179

TABLE 6

COMPARATIVE DATA AT SECONDARY PENDULUM BASES OCCUPIED

San Francisco, California, U.S.A.	
USC&GS Sta. #54 from New Jersey Ave. Base (corrected)	979.9640
Woollard from Commerce Base, Washington, D.C., U.S.A.	.9737
Fort Mason, California, U.S.A.	
Vening Meinesz from DeBilt, Holland	979.9960
Woollard from Commerce Base, Washington, D.C., U.S.A.	.9963
Pearl Harbor, Hawaii	
Drake from Columbia Univ., New York, N.Y., U.S.A.	978.9380
Woollard from Commerce Base, Washington, D.C., U.S.A.	.9368
Honolulu, Hawaii	
USC&GS Sta. #1 from New Jersey Ave. Base, Washington, D.C., U.S.A.	978.9450
Woollard from Commerce Base, Washington, D.C., U.S.A.	.9430
Nui Long. Sta., Hawaii	
USC&GS Sta. #8 from Commerce Base, Washington, D.C., U.S.A. (mean of 5)	978.9550
Woollard from Commerce Base, Washington, D.C., U.S.A.	.9534
Waianae, Hawaii	
USC&GS Sta. #15 from Commerce Base, Washington, D.C., U.S.A.	978.0350
Woollard from Commerce Base, Washington, D.C., U.S.A.	.0310
USC&GS Sta. #16 from Commerce Base, Washington, D.C., U.S.A.	.0340
Woollard from Commerce Base, Washington, D.C., U.S.A.	.0297
Honolulu Port, Hawaii	
Vening Meinesz from DeBilt, Holland	978.9410
Woollard from Commerce Base, Washington, D.C., U.S.A.	.9410
Guam	
Vening Meinesz from DeBilt, Holland	978.5380
Woollard from Commerce Base (approx. reoccupation), Washington, D.C., U.S.A.	.5384
Fort McKinley, Phillipines	
USC&GS Longitude Station from New Jersey Ave. Base, Washington, D.C., U.S.A.	978.4050
Woollard from Commerce Base, Washington, D.C., U.S.A.	.3969
Manila, Phillipines	
USC&GS Sta. #. from New Jersey Ave. Base, Washington, D.C., U.S.A.	978.3670
Woollard from Commerce Base, Washington, D.C., U.S.A.	.3592
Manila Observatory, Phillipines	
USC&GS Sta. from New Jersey Ave. Base, Washington, D.C., U.S.A.	978.3720
P. LeJay from Paris, France	.3590
Woollard from Commerce Base, Washington, D.C., U.S.A.	.3614
Manila Port, Phillipines	
Vening Meinesz from DeBilt, Holland	978.3600
Woollard from Commerce Base, Washington, D.C., U.S.A.	.3559
Coco Solo, Panama, C.Z.	
Vening Meinesz from DeBilt, Holland	978.2510
Ewing and Hoskinson from Commerce Base, Washington, D.C., U.S.A.	.2730
Woollard from Commerce Base, Washington, D.C., U.S.A.	.2547
Teddington Nat. Phys. Lab. Base, London, England	
Bullard and Joly (least square adjustment)	981.1953
Woollard from Commerce Base, Washington, D.C., U.S.A.	.1971
Pierce Junction, Texas	
Humble Oil Co. from Commerce Base, Washington, D.C., U.S.A.	979.3095
Woollard from Commerce Base, Washington, D.C., U.S.A.	.3095
Cleveland, Texas	
USC&GS Sta. #407 from Commerce Base, Washington, D.C., U.S.A.	979.3380
McCullum and Brown (least square adjustment)	.3372
Woollard from Commerce Base, Washington, D.C., U.S.A.	.3369

EVALUATION OF POTSDAM NETWORK

Every effort was made through the Russian embassy in Washington, D.C., U.S.A., as well as through the Director of the Geodetic Institute in Potsdam, Germany, to secure permission to make a direct tie to this base which is in the Russian controlled sector of Germany. However, it was not possible to do so, and the Potsdam system was therefore evaluated indirectly through the national bases which had been tied directly to it. These bases were Copenhagen, Den-

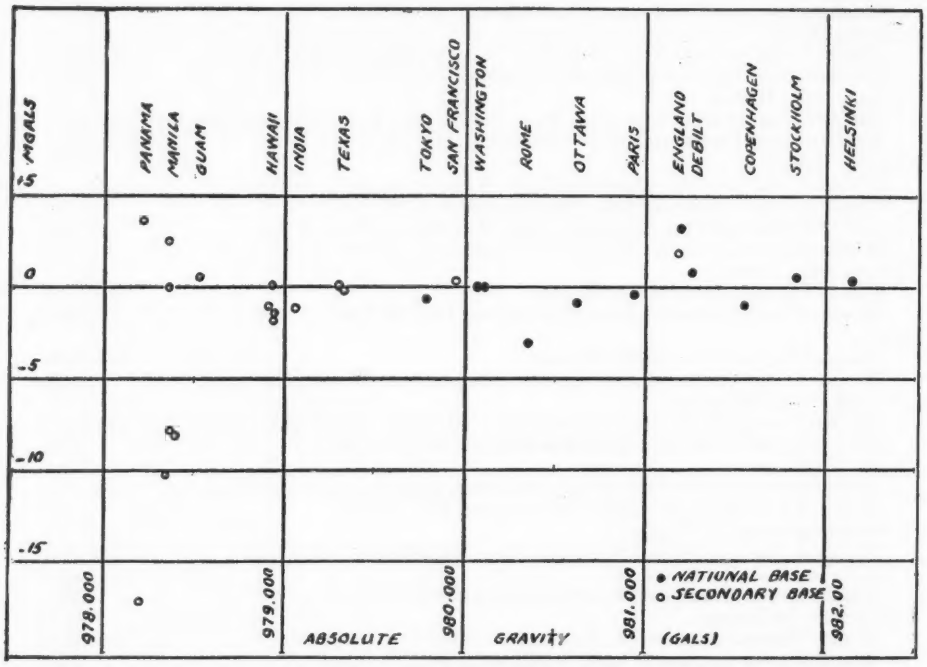

FIG. 8. Difference, pendulum and gravimeter, relative Commerce Base Washington.

mark, Stockholm, Sweden, Helsinki, Finland, DeBilt, Holland, Paris, France, Greenwich, England, Rome, Italy, Tokyo, Japan, Washington, D.C., U.S.A., and Ottawa, Canada. The number of direct and interlocking ties that had been made by pendulums between these bases is indicated in Figure 9.

The comparison between these various pendulum values and the gravimeter value with the mean of the adjusted values of Hirvonen and Morelli are summarized in Table 5 and are shown graphically in Figure 10. In most instances the gravimeter values agree well within one milligal with Hirvonen's and Morelli's adjusted values. However, in two instances, namely at Rome, Italy and at Washington, D.C., U.S.A., there are rather large differences. In the case of Washington, D.C., U.S.A., the base under consideration is the original New Jersey Ave. base in the present House Building. This base was connected to Pots-

dam, Germany by Putnam, Vening Meinesz, and Miller. The gravimeter values agree closely with Putnam's connection. The connection made by Brown (1936) between Potsdam, Germany and the Bureau of Standards and the Commerce Building Base in Washington, D.C., U.S.A., on the other hand was substantiated within a milligal by the gravimeter values. As indicated in Table 2 the error between these two bases in Washington, D.C., U.S.A., has been substantiated by other investigators. From the comparative data shown in Table 5 and Figure 9 the Bureau of Standards value of 980.100 is essentially a perfect connection with the Potsdam base.

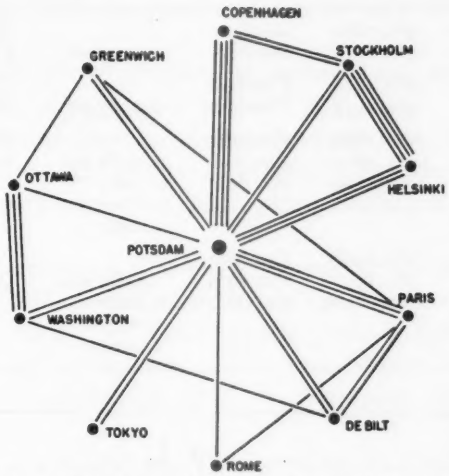

FIG. 9. Portion of Potsdam network occupied (exclusive of Potsdam)

EVALUATION OF ABSOLUTE GRAVITY MEASUREMENTS

Absolute gravity stations occupied were those of Heyl and Cook (1936) at the Bureau of Standards in Washington, D.C., U.S.A., and Clark (1939) at the National Physical Laboratory in Teddington, England. Indirectly the Potsdam absolute base value was checked through the various national bases which were directly tied to Potsdam.

The accuracy of the Potsdam, Germany value as compared to the other absolute bases will be considered first. Table 7 presents comparative data based on the gravimeter reoccupations.

TABLE 7

COMPARISON OF ABSOLUTE VALUES AT WASHINGTON AND TEDDINGTON WITH POTSDAM BASE VALUES

	Absolute Value	Potsdam Base Value, Woollard	Corr. for Elev. Diff.	Difference
Bureau of Standards	980.0800	980.0998	−0.2	+.0196
Teddington	981.1815	981.1961	0	+.0146

These ties indicate the Potsdam value is approximately 15 to 20 mgals high.

The accuracy of the Bureau of Standards and National Physical Laboratory values can be also considered on the basis of the relative difference in gravity between the two stations as determined from the absolute measurements and ties by different observers. These data are summarized in Table 8.

TABLE 8
COMPARATIVE DATA FOR GRAVITY INTERVAL BUREAU OF STANDARDS AND NATIONAL PHYSICAL LABORATORY

Station	Value	Basis	Difference	Observer
Bureau of Standards	980.0800	absolute		Heyl & Cook (1936)
Teddington	981.1815	absolute	1.1015 gal.	Clark (1939)
Bureau of Standards	980.1000	Potsdam		Brown (1936)
Teddington	981.1953	Potsdam	1.0953 gal.	Bullard & Joly (1936)
Bureau of Standards	980.0848	absolute		Browne & Bullard (1940)
Teddington	981.1815	absolute	1.0967 gal.	Browne & Bullard (1940)
	Correction	elv. diff.	+.0002	
			1.0969	
Bureau of Standards	980.0998	Potsdam		Woollard
Teddington	981.1961	Potsdam	1.0963 gal.	Woollard
	Correction	elv. diff.	+.0002	
			1.0965	

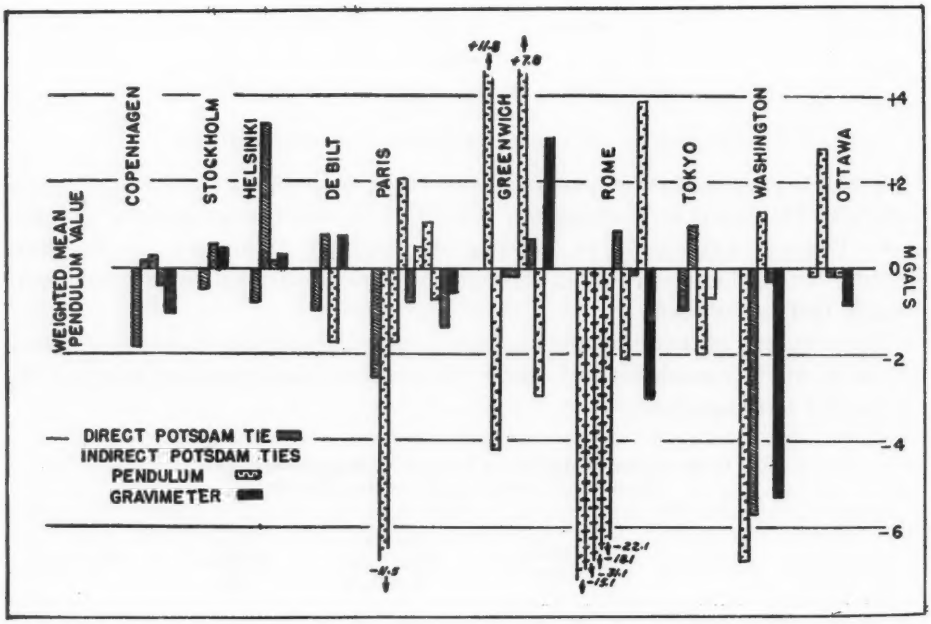

FIG. 10. Gravity determinations at national bases.

The two direct ties of Browne and Bullard (1940) and of the writer agree within 0.4 mgal, and indicate a probable error of approximately 5.0 mgals in the Teddington and Washington, D.C. absolute determinations. Although it had been hoped that an observation could be made at the site of the proposed absolute determination of gravity in Paris it was not found possible to do so.

CONCLUSIONS

Although the gravity meter used can not be regarded as the ultimate in design for longe range geodetic work, it did prove in general to be quite satisfactory. The over-all accuracy of the results obtained far exceeded both the writer's and manufacturer's expectations.

The principal drawbacks which were encountered and which were remedied in large measure by the manufacturer were:

(a) Tendency for the element to stick to the stops which frequently necessitated considerable "thumping" of the instrument to free the element.

(b) Very short battery life for the reading lamp under low temperature conditions.

(c) High center of gravity which made the instrument susceptible to being knocked over and difficult to read under windy conditions.

(d) Necessity for waiting, or removing the primary spring dial to remove condensation from the optical system surface when abrupt changes in temperature or humidity were encountered. This was frequently the case when using plane transportation.

(e) Establishment of a reliable constant between the readings of the primary and secondary spring dials.

(f) Occasional rather erratic drift behavior.

(g) Need for a hood when reading the instrument under very "bright" conditions.

The advantages of the instrument more than offset its drawbacks and are:

(a) Practically perfect temperature compensation.

(b) Wide range permitting observations to be made from pole to pole at sea level.

(c) High sensitivity (better than 0.1 mgal)

(d) Over-all linearity

(e) Nonmagnetic construction

(f) Freedom from barometric effects

(g) Ability to withstand low and high frequency vibrations without affecting readings.

(h) Low weight and size making it hand portable.

(i) Ability to withstand permanent damage occasioned by falls or mis-handling.

An apparent over-all accuracy of approximately ± 0.5 mgal was obtained during the world wide measurements in 1948. It is therefore planned to extend the

measurements to other parts of the world and gradually build up an integrated network of gravity stations that will ultimately permit a revaluation of the shape of the earth. Appendices A and B contain the principal facts for the new gravity stations, and their descriptions respectively.

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APPENDIX A

PRINCIPAL FACTS FOR NEW STATIONS ESTABLISHED

Station	Lat.	Long.	Elev. (Feet)	Observed Gravity	Sea Level	Elev. +Mass. Corr.	Theoretical Gravity	Bouguer Anomaly
Washington, D.C., U.S.A. National Airport	38°50.7′N	77° 2.9′W	17	980.1104	980.0783	.0010	980.0773	+.0331
Patuxent, Md., U.S.A. Naval Air Station	38°17.0	76°24.4	38	980.0250	980.0290	.0023	980.0267	−.0017
Norfolk, Va., U.S.A. Naval Air Station	36°55.8	76°17.7	15	979.8834	979.9111	.0009	979.9102	−.0268
Mitchel A.F. Base, U.S.A. Long Island	40°44.1	73°36.3	85	980.2427	980.2458	.0051	980.2407	+.0020
Westover, Mass., U.S.A. A.F. Base	42°11.8	72°32.1	244	980.3560	980.3768	.0146	980.3622	−.0062
Woods Hole, Mass., U.S.A.	41°31.2	70°39.4	20	980.3259	980.3161	.0012	980.3145	+.0114
Jacksonville, Fla., U.S.A. Naval Air Station	30°14.3	81°40.8	20	979.3673	979.3564	.0012	979.3552	+.0121
Dayton, Ohio, U.S.A. A.F.B. Patterson	39°48.3	84° 3.4	819	980.0925	980.1631	.0493	980.1138	−.0213
St. Louis, Mo., U.S.A. Airport	38°44.5	90°22.9	552	980.0078	980.0692	.0331	980.0361	−.0283
Pittsburgh, Pa., U.S.A. Airport	40°20.9	79°56.0	1252	980.0905	980.2114	.0751	980.1363	−.0458
Cleveland, Ohio, U.S.A. Airport	41°24.2	81°52.5	789	980.2327	980.3057	.0473	980.2584	−.0257
Chicago, Ill., U.S.A. Airport	41°47.3	87°45.9	618	980.2864	980.3401	.0371	980.3030	−.0166
Madison, Wis., U.S.A.	43°03.36	89°26.6	980	980.3534	980.4540	.0588	980.3952	−.0423
Memphis, Tenn., U.S.A. Airport	35° 3.4	89°58.8	269	979.7255	979.7504	.0161	979.7343	−.0148
Little Rock, Ark., U.S.A. Airport	34°44.1	92°13.8	257	979.7233	979.7231	.0154	979.7077	+.0088
Shreveport, La., U.S.A. Airport	32°32.5	93°39.1	179	979.5303	979.5409	.0107	979.5302	+.0001
Oklahoma City, Okla., U.S.A. Tinker AFB	35°25.2	97°22.9	1272	979.6723	979.7812	.0763	979.7049	−.0286
Houston, Tex., U.S.A. Airport	29°38.7	95°16.7	50	979.2932	979.3101	.0030	979.3071	−.0139
Denver, Colo., U.S.A. Lowry AFB	39°42.3	104°52.9	5412	979.6154	980.1543	.324	979.8296	−.2142
Ogden, Utah, U.S.A. Hill AFB	41°07.2	111°59.0	4788	979.7975	980.2803	.2873	979.9930	−.1955
Fairfield, Calif., U.S.A. Suison AFB	38°15.8	121°56.0	58	979.9893	980.0271	.0035	980.0236	−.0343
Mare Island, Calif., U.S.A. Naval Shipyard	38°07.1	122°17.1	10	979.9882	980.0145	.0006	980.0139	−.0257
Alameda, Calif., U.S.A. NAS	37°46.8	122°18.2	8	979.9849	979.9849	.0005	979.9844	+.0005
Moffett NAS, Calif., U.S.A.	37°24.9	122°03.0	41	979.9448	979.9530	.0025	979.9505	−.0057
John Rogers NAS Hawaii	21°19.2	157°55.15	6	978.9266	978.7301	.0004	978.7297	+.1969
Hickam AFB, Hawaii	21°20.35	157°57.50	21	978.9316	978.7313	.0013	978.7300	+.2016
Oahu H5	21°16.80	157°47.15	38	978.9533	978.7277	.0023	978.7254	+.2279
Oahu H6	21°17.15	157°44.10	12	978.9534	978.7281	.0007	978.7274	+.2260
Oahu H7	21°18.45	157°39.55	72	978.9531	978.7294	.0043	978.7251	+.2280
Oahu H8	21°20.00	157°42.40	13	978.9956	978.7315	.0008	978.7307	+.2649
Oahu H9	21°23.10	157°45.50	125	979.0356	978.7340	.0075	978.7265	+.3091
Oahu H10	21°25.95	157°44.60	10	979.0412	978.7369	.0006	978.7363	+.3049
Oahu H11	21°22.20	157°47.65	1190	978.9215	978.7331	.0714	978.6617	+.2598
Oahu H12	21°20.55	157°50.20	400	978.9553	978.7315	.0240	978.7075	+.2478
Pearl Harbor, Oahu	21°21.60	157°56.70	6	978.9368	978.7325	.0004	978.7321	+.2047
Oahu H14	21°23.85	157°59.50	100	978.9458	978.7348	.0060	978.7388	+.2070
Oahu H15	21°22.55	158°02.80	173	978.9016	978.7335	.0104	978.7231	+.2385
Oahu H16	21°20.25	158°05.50	81	978.9814	978.7312	.0049	978.7263	+.2551
Oahu H17	21°23.00	158°08.75	17	979.0122	978.7339	.0010	978.7329	+.2795
Oahu H20	21°28.00	158°09.00	280	979.0336	978.7391	.0168	978.7223	+.3113
Oahu H21	21°26.85	158°00.95	600	978.9295	978.7380	.0360	978.7020	+.2275
Oahu H22	21°32.60	158°02.55	1051	978.9028	978.7437	.0631	978.6806	+.2222
Oahu H23	21°35.05	158°06.40	18	978.9629	978.7404	.0011	978.7453	+.2176
Oahu H24	21°39.15	158°03.80	27	978.9517	978.7505	.0016	978.7489	+.2028
Oahu H25	21°41.75	158°01.40	12	978.9607	978.7531	.0007	978.7524	+.2083
Oahu H26	21°39.30	157°55.60	6	978.9688	978.7506	.0004	978.7502	+.2186
Oahu H27	21°36.65	157°54.65	6	978.9790	978.7480	.0004	978.7476	+.2314
Oahu H28	21°34.75	157°53.15	6	978.9854	978.7459	.0004	978.7455	+.2399
Oahu H29	21°29.20	157°50.85	8	979.0173	978.7403	.0005	978.7398	+.2775
Oahu H30	21°26.50	157°48.95	40	979.0311	978.7376	.0024	978.7352	+.2959
Johnston Island	16°44.2	169°30.9	7	978.7178	978.4760	.0004	978.4756	+.2422
Kwajalein Island	8°42.3	167°43.6′E	7	978.3647	978.1757	.0004	978.1753	+.1894
Harmon AFB, Guam	13°29.8	144°48.1	159	978.5261	978.3295	.0095	978.3200	+.2061
Cabros, Guam	13°27.8	144°41.1	5	978.5384	978.3282	.0003	978.3279	+.2105
Agana NAS, Guam	13°28.7	144°47.1	267	978.5219	978.3288	.0160	978.3128	+.2091
Opama NAS, Japan	35°19.0	139°39.7	6	979.7704	979.7724	.0004	979.7720	−.0016

APPENDIX A—(*continued*)

Station	Lat.	Long.	Elev. (Feet)	Observed Gravity	Sea Level	Elev. +Mass. Corr.	Theo-retical Gravity	Bouguer Anomaly
Tsingtao Observatory China	36°04.1′N	120°19.0′E	280	979.8151	979.8366	.0168	979.8198	−.0047
Edgewater Hotel Tsingtao, China	36°03.1	120°20.8	20	979.8306	979.8352	.0012	979.8340	−.0034
Tsangkou airport Tsingtao, China	36°09.6	120°23.1	25	979.8281	979.8446	.0015	979.8431	−.0150
TaMai Tao, China	36°04.8	120°25.2	35	979.8309	979.8377	.0021	979.8356	−.0047
Nan Yao, China	36°08.3	120°34.4	50	979.8300	979.8427	.0030	979.8399	−.0097
Priory Pass, China	36°11.3	120°36.5	2625?	979.7483	979.8470	.1575	979.6895	+.0588?
Shanghai airport	31°20.0	121°29.9	10	979.4550	979.4431	.0006	979.4425	+.0125
Nicols Field, Manila	14°31.8	121°00.7	16	978.3681	979.3732	.0010	979.3722	−.0041
Bangkok, Siam Airport	13°54.7	100°36.5	12	978.3274	978.3468	.0007	978.3461	−.0187
Calcutta, India Dum Dum Airport	22°38.4	88°26.3	14	978.8050	978.8123	.0008	978.8115	−.0065
Gaya, India Airport	24°44.2	84°57.0	370	978.8799	978.9513	.0222	978.9291	−.0492
Allahabad, India Bamrambi Airport	25°26.6	81°44.0	319	978.9437	979.0002	.0193	978.9809	−.0372
Cawnpore, India Chakeri Airport	26°24.1	80°25.0	410	978.9753	979.0679	.0246	979.0433	−.0680
Willingdon Airport New Delhi, India	28°36.7	77°12.7	693	979.1357	979.2310	.0417	979.1893	−.0536
Imperial Hotel New Delhi, India	28°37.5	77°13.1	695	979.1371	979.2320	.0417	979.1903	−.0532
Rohdab Road New Delhi, India	28°35.5	77°09.7	799	979.1327	979.2289	.0474	979.1815	−.0488
Surveyors Office New Delhi, India	28°41.1	77°13.5	701	979.1466	979.2366	.0421	979.1945	−.0479
Palam Airport New Delhi, India	28°35.4	77°7.4	720	979.1431	979.2294	.0432	979.1862	−.0431
Karachi, Pakistan Airport	24°54.1	67°9.6	75	978.9601	978.9626	.0045	978.9581	+.0020
Dhahran, Saudi Arabia Airport	26°16.4	50°10.0	79	978.9962	979.0588	.0047	979.0541	−.0579
Ras Mishaab, Saudi Arabia Airport	28°01.4	48°51.8	20	979.1694	979.1869	.0012	979.1857	−.0163
Abu Hadriyah, Saudi Arabia Airstrip	27°19.7	48°59.3	80	979.1091	979.1353	.0048	979.1305	−.0214
Khartoum, Soudan RAF Base	15°36.5	32°34.8	1250	978.3028	978.4218	.0750	978.3468	−.0440
Tripoli Wheelus AFB	32°54.4	13°15.9	17	979.5865	979.5707	.0010	979.5697	+.0168
Castel Benito, Tripoli RAF Base	32°41.25	13°09.0	78	979.5399	979.5511	.0047	979.5464	−.0065
El Azizia, Tripoli R.R. Station	32°31.85	13°00.9	410	979.5133	979.5403	.0229	979.5174	−.0041
BuOheliar, Tripoli Police Station	32°16.3	13°01.7	1188	979.4318	979.5186	.0713	979.4473	−.0155
Pt. Lyautey, Fr. Morocco NAS	34°17.1	6°34.9	16	979.6514	979.6854	.0010	979.6844	−.0330
Athens, Greece Airport	37°54.5	23°43.7	62	980.0606	979.9961	.0037	979.9924	+.0682
Rome, Italy Ciampino Airport	41°47.9	12°36.0	375	980.3481	980.3410	.0225	980.3185	+.0296
Rhein Main, Germany AFB	50°2.7	8°35.5	369	981.0590	981.0826	.0221	981.0605	−.0015
Wiesbaden, Germany AFB	50°3.3	8°20.9	456	981.0626	981.0835	.0274	981.0561	+.0065
Amsterdam, Holland Airport	52°19.0	4°47.8	−10	981.2873	981.2832	.0006	981.2846	+.0047
Copenhagen, Denmark Kastrup Airport	55°37.2	12°39.9	6	981.5568	981.5670	.0004	981.5666	−.0098
Stockholm, Sweden Bromma Airport	59°20.8	17°56.4	27	981.8467	981.8724	.0016	981.8708	−.0241
Helsinki, Finland Malmi Airport	60°15.3	25°3.0	49	981.9222	981.9438	.0029	981.9407	−.0185
Paris, France LeBourget Airport	48°57.3	2°26.9	145	980.9499	980.9854	.0087	980.9767	−.0268
London, England Northolt Airport	51°31.9	0°25.0′W	112	981.2085	981.2142	.0067	981.2075	+.0010
Marham, England RAF Base	52°39.0	0°33.8′E	80	981.3124	981.3122	.0048	981.3074	+.0050
Lyneham, England RAF Base	51°30.9	1°58.6′W	440	981.1720	981.2127	.0264	981.1863	−.0143
Keflavik, Iceland Airport	63°58.7	22°36.0	107	982.2736	982.1500	.0100	982.1400	+.0336
Reykjavik, Iceland Harbor	64°08.8	21°57.0	8	982.2803	982.1526	.0005	982.1521	+.0282
Goose Bay, Labrador AFB	53°18.8	60°25.1	150	981.3085	981.3698	.0090	981.3608	−.0523
Stephenville, Newfound-land AFB	48°32.6	58°32.6	22	980.9328	980.9486	.0013	980.9473	−.0145
Lagens, Azores AFB	38°45.2	27°5.6	170	980.1772	980.0702	.0102	980.0600	+.1172
Bordeaux, France Merignac Airport	44°50.6	0°42.7	155	980.5777	980.6150	.0093	980.6057	−.0280
London, England Hendon Airport	51°36.0	0°13.1	160	981.2076	981.2203	.0096	981.2107	−.0031

REFERENCE POINTS OCCUPIED AND THEIR OBSERVED GRAVITY VALUES

Boston, Mass., U.S.A.	
South Station	980.3979
Calcutta, India	
Great Eastern Hotel	978.8023
Houston, Texas, U.S.A.	
Houston Technical Laboratory	979.2989
London, England	
Grosvenor Square	981.2011
New York, N.Y., U.S.A.	
Empire State Building (Ground Floor)	980.2668
Empire State Building (80th Floor)	980.1686
Pennsylvania Station	980.2675
Grand Central Station	980.2685
Princeton, New Jersey, U.S.A.	
4 Queenston, Place	980.1775
Guyot Hall	980.1790
San Francisco, California, U.S.A.	
Federal Building	979.9926
Golden Gate Park	979.9858
Washington, D.C., U.S.A.	
National Airport (2)	980.1098
Washington Monument (base)	980.1150
Washington Monument (top)	980.0681
Union Station	980.1169
Woods Hole, Mass., U.S.A.	
Little Harbor Road	980.3259

No data or descriptions are included for billets and hotel rooms used only for purposes of drift control because of the uncertainty of elevation and position and anticipated difficulty in reoccupying such sites.

The local descriptions for the stations listed in appendix A are attached as appendix B to this report.

APPENDIX B

DESCRIPTION OF NEW GRAVITY STATIONS

Abu Hadriya, Saudi Arabia—Airport

At base of wind sock mast on runway level.

Alameda, California—Naval Air Station

To right of back door leaving terminal building waiting room on ground level.

Allahabad, India—Bamrambi Airport

On lower step of portico, leading to lounge of terminal building from runway.

Amsterdam, Holland—Schiphol Airport

On floor to left of inner door entering new terminal building from runway.

Athens, Greece—Ellinikon Airport

On floor in corner by fireplace of lounge of terminal building used by U. S. Military Air Transport Service.

Azores (see Tercieras)

Bangkok, Siam—Don Among Airport

On floor about 150 ft. inside terminal hanger door and just outside entrance to Operations Office of Pan American Airways.

Bordeaux, France—Merignac Airport

On ground at edge of runway about 50 ft. from control tower and on a line between control tower and entrance to terminal building across runway.

Boston, Mass., U.S.A.—South Station
On floor at East end of waiting room in telephone alcove on far side of desk of switchboard operator.

BuOheilar, Tripoli—Police Station
On road level by rock bordered flower plot in front of entrance to personnel quarters.

Calcutta, India—Dum Dum Airport
On step at entrance from runway to immigration office for incoming passengers.

Calcutta, India—Great Eastern Hotel
On floor of entrance foyer from street to lobby opposite registration desk.

Cawnpore, India—Chakeri Airport
On ground off runway beneath isolated group of large shade trees used as terminal by Bharat Airways.

Chicago, Illinois, U.S.A.—South Chicago Commercial Airport
On floor in hall on street side of terminal building at entrance to Capital Airlines baggage room.

Cleveland, Ohio, U.S.A.—Commercial Airport
On runway to right of gate directly in front of control tower.

Copenhagen, Denmark—Kastrup Airport
On floor (under shed) to right of entrance from runway to immigration office for incoming passengers.

Dayton, Ohio, U.S.A.—Patterson Air Force Field
On ground to right of steps entering terminal building from runway.

Delhi, India—Willingdon Airport
On cement just outside incoming passenger entrance to terminal building from runway.

Delhi, India—Palam Airport
On runway just outside entrance to terminal building.

Delhi, India—Imperial Hotel
On right hand side of hall entering hotel from principal carriage door (Queensway) at top of steps and at lobby level

Delhi, India—Surveyor General's Office
On concrete porch to right of entrance to Surveyor General's Office in old government block in Old Delhi.

Delhi, India—Rohdab Road
On circular cement platform in middle of junction of Station Road and Rohdab Road on way to Palam Airport.

Denver, Colorado, U.S.A.—Lowry Air Force Base
On edge of runway at volley ball court net in front of terminal building.

Dhahran, Saudi Arabia—Air Force Base
On floor on left side of entrance vestibult into terminal building from runway.

El Azizia, Tripoli—Railway Station
In front of south door from road into railway station at ground level at edge of porch.

Fairfield, California, U.S.A.—Fairfield—Suison Air Force Base
On edge of runway by fire hydrant at baggage truck entrance to terminal building.

Frankfurt, Germany—Rhein Main Air Force Base
On runway level at foot of steps outside of terminal door leading to Gates 1, 2, 3 and 4.

Gaya, India—Commercial Airport
On concrete step outside entrance to meteorological office from runway.

Goose Bay, Labrador—Goose Bay Air Force Base
At edge of runway and to right of stairs leading to entrance of terminal building from runway.

Guam, Marianna Islands—Harmon Air Force Base
On floor in terminal building to right of Gate 1 leading to runway.

Guam, Marianna Islands—Agana Naval Air Station
On floor in terminal building to right of Gate 1 leading to runway.

Guam, Marianna Islands—Hoover Park
On ground, inside and to the left of entrance to Hoover Park from causeway road to Cabros Island.

Helsinki, Finland—Malmi Airport
On floor in rotunda of terminal building directly opposite entrance to passport inspection office for departing passengers.

Honolulu, Hawaii—John Rogers Naval Air Station
On pavement on road side and to the right of the entrance to terminal building.

Honolulu, Hawaii—Hickam Air Force Base
On pavement and to right of U.S. Customs Office off court on runway side of terminal building and just outside briefing room.

Houston, Texas, U.S.A.—Commercial Airport
On pavement just inside barrier at Gate 4 leading from terminal to runway.

Jacksonville, Florida, U.S.A.—Naval Air Station
At edge of runway by fence and to left of walk leading to entrance of terminal building from runway.

Johnston Island—Military Air Base
On walk about 12 feet to left of entrance of terminal building from runway.

Karachi, Pakistan—Commercial Airport
On walk, on left, and just inside portal leading from runway to control tower.

Keflavik, Iceland—Meeks Field
On ground to left of entrance shelter from runway to terminal building.

Khartoum, Anglo-Egyptian Soudan—RAF Base
On ground at corner of hangar 26 nearest gate leading to runway.

Kwajalein, Marshall Islands—Air Force Base
In terminal building on pavement at front edge, center, of shrubbery plot nearest door leading to runway.

Little Rock, Arkansas, U.S.A.—Commercial Airport
On runway to left of Gate 1 leading from runway to terminal building.

London, England—Hendon Airport
On ground to left of door leading from runway into lounge of terminal building.

London, England—Northolt Airport
In customs room to right of door leading to waiting room for departing passengers.

London, England—Grosvenor Square
On floor on left side of center alcove of entrance foyer to U.S. Naval Headquarters from side street.

Lyneham, England—RAF Base (near Swindon)
On floor in far corner of reception room for incoming passengers diagonally across from runway entrance.

Madison, Wisconsin, U.S.A.—3291 Winnemac Avenue
On concrete slab to right of street entrance into living room.

Manila, Philippine Islands—Nicols Field
On floor in far corner from entrance of Pan American Airways office in terminal building.

Mare Island, California, U.S.A.—Naval Shipyard
On ground 20 ft. west of North Gate Sentry Post.

Marham, England—RAF Base (near Downham Market)
At edge of runway directly in front of room for incoming baggage and mail for U.S. personnel.

Memphis, Tenn., U.S.A.—Commercial Airport
On runway to right of Gate 5 leading to terminal building.

Mitchell Field, Long Island, New York, U.S.A.—Air Force Base
On walk at base of control tower.

Moffett, California, U.S.A.—Naval Air Station
On hangar floor at right hand side of terminal hangar door going on to runway.

Nan Yao, Shantung Peninsula, China
On ground at base of sign post at intersection of road leading inland and coast road about 1 mile west of village of Nan Yao.
New Delhi (see Delhi)
New York, New York, U.S.A.—Pennsylvania Station
On floor in main lobby at base of stairs leading up to 31st Street and to right of office door of Pennsylvania R.R. Travel Bureau Office.
New York, New York, U.S.A.—Grand Central Station
On floor in corner of concourse between Gates leading to tracks 30 and 32.
New York, New York, U.S.A.—Empire State Building (1)
On floor at street level just outside door to barber shop next to Post Office.
New York, New York, U.S.A.—Empire State Building (2)
On floor of 80th floor in back of elevator shaft and opposite entrance to room 8001.
Norfolk, Virginia, U.S.A.—Naval Air Station
On pavement at left side of steps leading into terminal building.
Ogden, Utah, U.S.A.—Hill Air Force Base
On runway at right hand side of steps leading into terminal building.
Oklahoma City, Oklahoma, U.S.A.—Tinker Air Force Base
On runway directly in front of entrance into terminal building.
Ottawa, Canada—Dominion Observatory
On concrete slab at foot of steps leading up to main entrance into Observatory.
Patuxent, Maryland, U.S.A.—Naval Air Station
On floor, on runway side of terminal building at barrier across lounge.
Paris, France—LeBourget Airfield
On floor and just inside entrance from runway to passport control room for incoming passengers.
Pearl Harbor, Hawaii—Submarine Base
On deck at head of pier 6.
Philadelphia, Pennsylvania, U.S.A.—Broad Street Station
On platform at rail head to right of Gate 4.
Pittsburgh, Pennsylvania, U.S.A.—Commercial Airport
On runway to left of Gate 1 leading to terminal building.
Port Lyautey, French Morocco—Naval Air Station
On walk alongside terminal building between entrances to Operations Office and Waiting Room.
Princeton, New Jersey, U.S.A.—4 Queenston Place
On hearth of living room fireplace
Princeton, New Jersey, U.S.A.—Guyot Hall
On center laboratory table in Room 15 of basement floor.
Priory Pass, Shantung Peninsula, China
On ground at crest of road pass through mountains at ruins of Russian orthodox church priory about 4 hours drive from Tsingtao.
Ras Mishaab, Saudi Arabia—Air Strip
On runway at fence opposite customs office shed.
Reykjavik, Iceland—Harbor
On deck at center of seaward end of concrete of Long Pier.
Rome, Italy—Ciampino Airport
On ground in runway corner of court yard for departing passengers between terminal building and runway away from courtyard entrance.
Rome, Italy—School of Engineering Faculty Building (1)
On street level at right hand side of staircase leading from street up to building level
Rome, Italy—School of Engineering Faculty Building (2)
On floor level just inside corridor flanking patio to left of main entrance.
San Francisco, California, U.S.A.—Federal Building
On floor at foot of staircase leading up from ground floor at corner entrance off Civic Center Plaza used as loading point by Navy buses.

San Francisco, California, U.S.A.—Golden Gate Park
On bench at rear of machine shop in Academy of Science Building.
Shanghai, China—Kuangwan Airport
On runway level at foot of steps leading into waiting room of terminal building.
Shreveport, Louisiana, U.S.A.—Commercial Airport
On runway to left of Gate 1 leading to the terminal building.
Springfield, Massachusetts, U.S.A.—Railroad Station
On level of Platform No. 1 about 100 ft. toward end of platform beyond the elevator.
St. Louis, Mo., U.S.A.—Commercial Airport
On runway to left of Gate 2 leading to terminal building.
Stephensville, Newfoundland—Harmon Air Force Base
On runway level at right side of entrance into terminal building.
Stockholm, Sweden—Broma Airport
On floor in waiting Rm. 5 of terminal building by the customs counter.
Ta Maituo, Shantung Peninsula, China
On well coping by ford on east side of village.
Tercieras, Azores—Lagens Air Force Base
On runway level to right of steps leading into terminal building from runway.
Tokyo, Japan—Imperial Hotel
On table to right of entrance to bath in Room 278.
Tripoli, North Africa—Wheelus Air Force Base
On floor in center of terminal building waitin room about 14 feet in front of counter.
Tripoli, North Africa—Castel Benito Airport
On sidewalk immediately in front of sentry house to right of main entrance gate.
Tsingtao, China—University Observatory
On granite step of ground level entrance into observatory tower.
Tsingtao, China—Edgewater Hotel
On desk by French doors leading on to Balcony in Rm. 105.
Tsingtao, China—Tsangkou (U. S. Marine) Air Base
On floor in middle of terminal waiting room opposite door leading to runway.
Washington, D.C., U.S.A.—Washington Monument (1)
On pavement to right of entrance door.
Washington, D.C., U.S.A.—Washington Monument (2)
On floor of observatory (top) by door to small closet in exterior wall at back of elevator shaft.
Washington, D.C., U.S.A.—National Airport (1)
On pavement on runway side of Military Air Transport Service terminal just outside Gate 1 and next to U.S. Customs and Immigration Service Office.
Washington, D.C., U.S.A.—National Airport (2)
On pavement on runway side of main terminal building and to right of north baggage truck entrance.
Washington, D.C., U.S.A.—Union Station
On platform on concourse side to right of Gate 4.
Westover, Massachusetts, U.S.A.—Air Force Base (near Chicopee)
In corner of alcove of terminal waiting room next to rear door leading across tracks to cafeteria.
Wiesbaden, Germany—Air Force Base
On floor of porch by left hand pillar of entrance below control tower on runway side of terminal building.
Woods Hole, Massachusetts, U.S.A.—Oceanographic Institution
On bench by window in Room 106.
Woods Hole, Massachusetts, U.S.A.—Little Harbor Road
On hearth of living room fireplace.
Yokosuka, Japan—Opama Naval Air Station
On ramp just outside door to operations office.

COMPOSITE REFLECTIONS*

NORMAN RICKER† AND R. D. LYNN†

ABSTRACT

This paper discusses the development of a method of reflection seismic prospecting based on the use of the seismic *PS* phase—a disturbance which has traveled from the shot to the reflecting bed as a dilatational wave and from the reflecting bed to the earth's free surface as a shear wave, where it is picked up by horizontal component geophones. The reflection occurs on the seismogram in the otherwise quiet region between the dilatational waves and the ground roll and thus is never obscured by the ground roll. The reflection is quite clear and capable of spot correlation from spread to spread.

The use of the method in delineating the Homer and Cotton Valley structures, near Minden, Louisiana, is described in detail. The method appears to be applicable to regions where an unconsolidated subsurface extends downwards from the earth's surface to a single hard bed serving as a reflector. Criteria for identifying the disturbance as a composite reflection are given and the advantages and limitations of the method are discussed.

INTRODUCTION

During the course of certain fundamental studies on the propagation of seismic waves in shale beds east of Tulsa, Oklahoma, a very prominent and well isolated disturbance was observed. Its arrival time lay in the comparatively quiet region between the arrival of the primary disturbance (waves of dilatation) and the arrival of the ground roll. This well isolated disturbance, was picked up strongly by horizontal-component geophones (laid with their direction of response along the line from the shot point), but scarcely at all by vertical-component geophones. It was suspected as being a disturbance which had started as a wave of dilatation, but had been reflected as a shear wave, the evidence being the horizontal in-line motion of the received vibration and the time of arrival of the disturbance. During further studies in the Mississippi Gulf Coastal region near Hattiesburg, Mississippi, this disturbance again was observed in a very beautiful and well developed form (see Fig. 9). Feeling that this particular disturbance (which has been termed a composite reflection because of its two-fold nature) might possibly be of value in prospecting, a second trip was made to the Hattiesburg area. This trip was made specifically for the purpose of identifying the disturbance and studying such matters as hole to hole and spread to spread correlations and the ability of the disturbance to reveal variations in depth of a reflecting surface.

During this trip the early suspicions as to the nature of the disturbance were confirmed. The disturbance showed excellent hole to hole correlation. Phenomena observed in the spread-to-spread correlations further identified the disturbance as a true composite reflection, and depth checks against the four wells available as control points and against regional dip were satisfactory.

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Following this identification of the composite reflection, short trips were made to Waurika, Oklahoma, and to Aberdeen, Mississippi, to see if disturbances appearing to be composite reflections could be observed in these areas. Such disturbances were observed on the seismograms, although the brief nature of the trips did not permit positive identification of the disturbances to be made.

After these encouraging early studies it was decided that a program should be gotten under way for evaluating these composite reflections as an exploratory tool. Accordingly, composite reflection studies in varying degrees of completeness were carried out by a fully equipped seismic party at:

1. The Ramsey, Lucien, and Orlando structures near Stillwater, Oklahoma;
2. The Village structure near Magnolia, Arkansas;
3. The Homer and Cotton Valley structures near Minden, Louisiana;
4. In the vicinity of Aberdeen, Mississippi, east of the outcrops of Selma Chalk, and Tombigbee sandstone.

In the above areas the value of composite reflections as a prospecting means could be demonstrated only at Village, Homer, and Cotton Valley. In the Homer and Cotton Valley area a rather complete survey was made and this survey is used in this paper to demonstrate the use of composite reflections in prospecting.

It is felt that these composite reflections are of value in regions where thick unconsolidated formations are underlain by a good velocity discontinuity—experience being that such a bed gives rise to composite reflections.

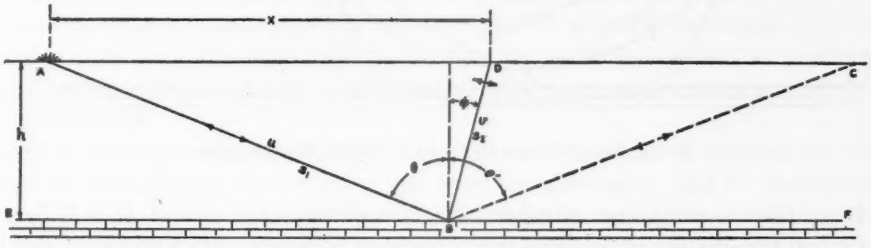

FIG. 1. Dilatational and shear reflections from incident dilatational disturbance.

COMPOSITE REFLECTIONS

When a charge of explosive is fired at a point below the earth's free surface, as at *A* in Figure 1, waves are created which spread out from the shot point. In a solid body two types of waves pass through the body of the material. One type, known as a dilatational wave, causes an earth particle over which it passes to vibrate back and forth along the line of travel of the wave—that is, along the ray path. For this reason this wave is sometimes called a "longitudinal wave," since the vibration lies along the direction of travel. The other type of wave is called a wave of shear and causes an earth particle over which it passes to vibrate back and forth transverse to the line of travel of the wave. For this reason this wave it sometimes called a "transverse wave." The forces responsible for the propagation

of a dilatational wave are due to the combined elastic moduli of compression and shear, while the forces responsible for the propagation of a wave of shear are due to the elastic modulus of shear alone. Hence, the wave of dilatation travels much faster than the wave of shear and is first to arrive at a distant point. In Figure 1 a line of travel of the dilatational wave is shown by the line AB. Let us suppose that at some depth, h, below the earth's free surface there lies a surface of discontinuity EF. As the dilatational wave strikes this reflector at B, part of the energy of the wave is reflected along the direction BC so that the angle of reflection θ' is equal to the angle of incidence θ. This regularly reflected wave is also a wave of dilatation. However, in addition to this regularly reflected dilatational wave there is another wave reflected by the bed EF. This wave travels along the direction BD and is a wave of shear. Since the velocity of this shear wave is much lower than the velocity of the dilatational wave, this wave is not regularly reflected, but comes off in a direction making an angle ϕ with the vertical. The angle ϕ is determined by the simple relation $\sin \phi/v = \sin \theta/u$; where u is the velocity of dilatational waves in the upper medium, and v is the velocity of shear waves in that medium. Refracted waves of both types in the lower medium also exist, but are not relevant hereto.

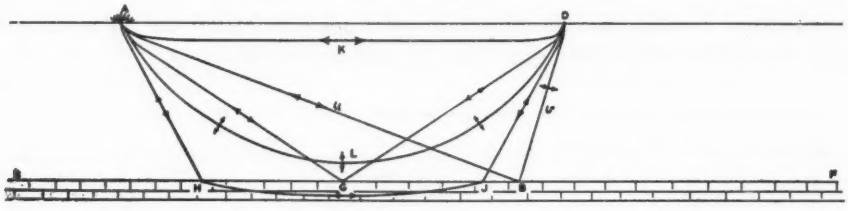

FIG. 2. Paths of various types of seismic disturbances.

If we place a geophone, or other vibration detecting device at D, it is found that when this wave arrives the earth vibration is very nearly horizontal and in line with the shot, due to the transverse nature of the wave upon arrival. This type of reflection is called a "composite reflection" since it has a two-fold nature, the wave traveling during the first part of its path as a dilatational wave and during the remainder of its path as a shear wave.

In Figure 2 are shown the ray paths of various waves arriving at a geophone placed at D and due to an explosion at A.

In the order in which these waves arrive at D we have

1. The refracted dilatational wave. This wave is shown by the path $AHJD$. The wave is dilatational during all three parts of its path. This is the wave of ordinary refraction prospecting.
2. The direct dilatational wave. This wave takes the path AKD. (For short distances between shot and geophone this wave arrives first.)
3. The reflected dilatational wave. This wave takes the path AGD and is the wave of ordinary reflection prospecting.

4. The composite reflection. This wave is shown by the path *ABD* and forms the subject of this paper.
5. The direct shear wave. This wave takes the path *ALD*, which is concave upward due to the shear velocity gradient which usually exists in the earth, and is usually difficult to distinguish from the first part of the so-called "ground roll" disturbance.

The ray paths of all of these waves upon reaching *D* come up nearly vertically from below. Hence, those waves which complete their travel as waves of dilatation are received strongly by vertical-component geophones, but to a much lesser extent by horizontal-component geophones. On the other hand, those waves which complete their travel as waves of shear are received strongly by horizontal-component geophones, but only very feebly by vertical-component geophones. This is well illustrated by record No. 1, Figure 10. The various disturbances are identified in the plate legend. It will be noticed that the composite reflection is very well isolated and clearly defined. This is due to a number of causes:

1. The horizontal in-line polarization of the vibration and the use of geophones sensitive to this vibration bring out the shear waves (of which the composite reflection is the first member) and suppress the dilatational waves.
2. The composite reflection arrives at a time after the dilatational waves have passed and the "ground roll" has not yet arrived.
3. The composite reflection is selective as to distance from the shot point, a matter which will be discussed below. This means that there is a distance from the shot at which the composite reflection is most strongly developed, and that other possible composite reflections from minor stratifications at shallower depths are suppressed due to unfavorable shot to geophone distance for these disturbances.

When observations are made with horizontal-component geophones set with their direction of response along the line from the shot point and at various distances from the shot point, it will be found that at short distances the composite reflection is too feeble to observe. Upon moving outward, however, upon reaching a certain critical distance the composite reflection suddenly appears strongly. This sudden appearance generally occurs when the distance from shot to geophone is between two and three times the depth of the reflector. This appearance of the reflection is so sudden that with a set of six horizontal geophones placed at 200-foot intervals the first three traces may not show the reflection at all, while the last three traces may show it very prominently developed. As the distance is further increased the reflection gradually falls off in prominence. This phenomenon seems to be in accordance with what is known about reflection coefficients at various angles of incidence.

FIELD EQUIPMENT FOR USE WITH COMPOSITE REFLECTIONS

In the work described in this paper the equipment differed in certain respects from that used in ordinary dilatational reflection prospecting. These differences are essentially as follows:

1. Since the composite reflection arrives as a shear disturbance, horizontal geophones were used instead of the usual vertical-component geophones, and were set with their direction of maximum response along the shot line.
2. Since the predominant frequencies in the composite reflection are low (of the order of 10 cycles per second) it was thought desirable to avoid transformers, and so geophones with a high impedance winding were used so as to deliver a satisfactory input voltage to the amplifiers without the use of transformers.
3. Also, due to the low frequencies peculiar to composite reflections, the geophones were designed to have a low natural frequency of the order of 1 to 1.5 cycles per second, and while these geophones were fairly well damped, it is felt that underdamped geophones would have introduced less distortion.
4. Due to the low frequencies involved, transformers were not used in the output circuit of the amplifiers, the galvanometers being placed in the cathode circuit of the amplifier output.
5. Amplifier filtering was of the high frequency suppression type, with rather sharp cut-off. An amplitude versus frequency characteristic expressed by

$$\text{Amplitude} = (\text{constant}) \cdot e^{-(f/10)^2}$$

was desired but was realized only approximately. The amplifier phase characteristic was rather poor. This high frequency suppression is called for to suppress some extraneous high frequency energy coming in at the composite reflection time region. However, variable high frequency suppression has been used and would probably be desirable in a new area. Low frequency suppression was not needed.
6. The recording camera and associated equipment was modified only slightly from that used for regular reflection recording. Since composite reflections are somewhat lower in frequency and have a later arrival time than regular dilatational reflections, the paper speed was reduced to about one-half the customary speed and 50 timing lines per second were used in place of the customary 100.
7. It was found desirable to place a vertical-component geophone at each end of the spread alongside the horizontal-component geophones—these vertical-component geophones being of the low-frequency high-impedance type and working through amplifying circuits of the same type as for the horizontal geophones—as one means of identification of the disturbance as a composite reflection, since the vertical traces should be reasonably quiet when the horizontal traces respond to the composite reflection.

FIELD OPERATIONS WITH COMPOSITE REFLECTIONS

In the experiences with composite reflections reported here, good reflections were secured in regions where unconsolidated sands, gravels, and shales extended from the earth's surface down to a good reflecting bed. There was no evidence of

composite reflections from beds lying below this first bed, although this particular matter was not investigated thoroughly.

In going into a new area for the purpose of operating with composite reflections it has been customary to run first, two to four long profiles with both vertical and horizontal in-line geophones from the shot point out to a distance of say five times the supposed depth of the reflecting bed. These profiles enable a determination both of the dilatational and shear wave velocities to be made. Also, from these profiles the depth of the first refracting surface was determined. Further, in the course of running these profiles, the horizontal-component geophones picked up the composite reflection at a point beyond some critical distance. Before proceeding further it was necessary to identify these supposed composite reflections as true composite reflections. For this identification there were a number of criteria to be satisfied:

1. The traces of the vertical-component geophones should be reasonably quiet at the time the reflection appears on the traces from the horizontal-component geophones. This tends to establish the shear wave nature of the disturbance upon arrival at the geophone.
2. The arrival time of the event should lie between the dilatational waves and the ground roll.
3. Upon plotting the time-distance curve for the event, the apparent velocity as determined from this curve should not be less than u, the velocity of dilatational waves in the medium above the reflector.
4. Upon making a graphical chart similar to Figure 1 of the sub-surface geometry, scaling the lengths AB and BD and measuring the angles θ and ϕ, and using observed values of h, u, and v from the refraction data, it should be possible to determine a position of the point B such that $AB/u+BD/v=T_c$, where T_c is the travel time of the event, and $\sin\theta/u=\sin\phi/v$.

If these criteria were satisfied approximately, it generally was concluded that the event was a true composite reflection. (By "approximately" is meant equality within say 10 percent in the time equation, assuming the angular relations satisfied exactly; better agreement cannot generally be expected due to the uncertainty in the depth and velocity figures from the refraction work.)

The layout of shot points used was similar to that commonly used in correlation work with the regular technique, namely one to one and one-half mile spacing. The exact placement of course depended on road conditions and other considerations.

As to the number of geophones, six geophones spaced about 200 feet apart were found satisfactory. Vertical-component geophones at the end stations were also needed, thus yielding an eight-trace record. Compositing was not found necessary or desirable. The optimum distance of the first geophone from the shot was fixed by reference to the results for the long profiles mentioned above.

The shooting technique used was that of the regular method, i.e., with shots in 20–100 foot drilled holes, except that slightly larger charges were required.

APPLICATION OF COMPOSITE REFLECTION METHOD TO THE HOMER-COTTON VALLEY AREA

Field Procedure—This northwestern Louisiana work was carried out in the period June 4–July 31, 1941, using a fully staffed and fully equipped experimental seismograph party. The equipment used, and the field procedure employed, followed the discussions already given closely enough that very little further detailed explanation seems called for. The long profiles run showed the optimum reflection distance to be about 5,500 feet, so that the spreads were thereafter centered using this distance as a criterion as closely as road conditions permitted.

The reflection points were placed as evenly as the road distribution permitted, though certain lines were concentrated upon with the view toward studying various correction techniques. Also, several locations were made by wells for control purposes. All shot and depth point locations are indicated on Figures 12 and 13 together with the more reliable well depths.

Shot depths ranged from 20 to 110 feet, being determined in the usual fashion, i.e., by the desire to find a fairly solid shale bed in which to shoot. Dynamite charge ranged generally from 5 to 20 pounds.

While a few "weathering shots" were taken, the practice was not followed consistently. Instead, corrections were based on the arrival time of the direct shear wave on the regular record, as described below.

The reflection records obtained were generally satisfactory, particularly with reference to certainty of reflection correlation. Several records are shown in Figure 10. Traces 1 and 8 are from vertical-motion geophones, beside the horizontal-motion geophones responsible for traces 2 and 7, respectively. The arrivals of the various wave groups are indicated as follows: (a) direct dilatational waves; (b) composite reflection; (c) direct shear wave. It will be noticed that at the time the horizontal geophones respond to the composite reflection the vertical geophones show no appreciable disturbance. This also is true for the direct shear wave. At the time the primary dilatational disturbance arrives, the vertical geophones respond much more than the horizontal geophones to this disturbance, although the dilatational disturbance still appears on the horizontal geophones. On some seismograms, however, the horizontal geophones do not show this dilatational disturbance.

Additional composite reflection seismograms are shown in Figure 11, these seismograms being made at Hattiesburg, Mississippi and at Waurika, Oklahoma. On seismogram No. 2 of this figure, the failure of horizontal cross-line geophones to pick up the composite reflection is clearly seen. This establishes the horizontal in-line polarization of the composite reflection vibration as received at the earth's surface.

Interpretation—There are two elementary procedures for determining reflector depths by means of composite reflections. The first of these may be termed the empirical method and implies a knowledge of the depth of the reflector at certain control stations, from well logs or other sources of information. The sec-

ond may be termed the rational method, which involves a determination of wave velocities and approximate depth of the reflector from refraction studies and a calculation of depths from the composite reflection travel time by means of a formula. In both of these methods the dilatational wave velocity shall be considered as holding constant while variations in shear velocity (see below) must be allowed for; since it has been found that there is a considerable variation in velocity of the shear wave at different places over an area.

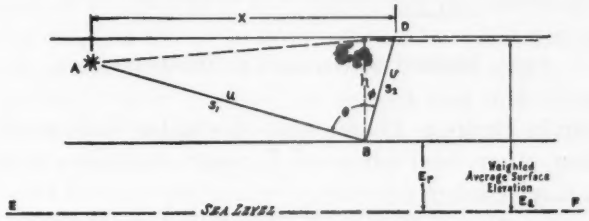

FIG. 3. Subsurface geometry of composite reflection.

THE EMPIRICAL METHOD OF INTERPRETATION

Referring to Figure 3, elevations will be given with respect to sea level. Let E_r be the elevation of the reflector and let E_a be the elevation of a point directly above the reflection point B and lying on the line joining shot and geophone. This point lies in from the geophone at a distance approximately

$$(\tan \phi/\tan \theta + \tan \phi)(X)$$

toward the shot. In the survey of Homer and Cotton Valley this distance has been taken as $X/6$. It is not necessary to know this point very accurately, as it merely determines the position of the reflection point on the map. The elevation E_a has been called the weighted average elevation and is determined by

E_a = elev. of geophone − $(\tan \phi/\tan \theta + \tan \phi)$ · (elev. of geophone − elev. of shot).

Or in the survey of Homer and Cotton Valley

$$E_a = \text{elev. of geophone} - 1/6 \text{ (elev. of geophone} - \text{elev. of shot)}.$$

We have then

$$h = E_a - E_r.$$

Presuming for the moment that both the dilatational and shear velocities remain constant over the area being surveyed, and knowing the value of h at a number of control stations from well log data or other information, the arrival time T_c of the composite reflection may be determined for these stations at a fixed distance X from the shot point. When this has been done, h should be a function of T_c and the points from the observations may be plotted on coordinate

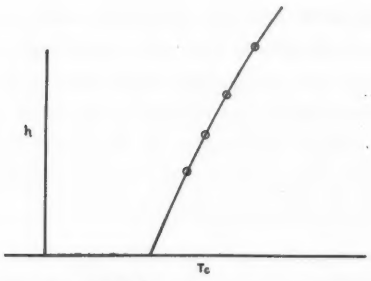

FIG. 4. Idealized reflector depth vs. travel time curve.

paper as is shown in Figure 4. These points should lie nicely on a smooth curve. Accordingly, then, other observations of T_c made at stations removed from the control stations may be referred to this curve and the value of h read off the curve. Knowing E_a, the elevation of the reflector should then be obtained from

$$E_r = E_a - h.$$

The above is the idealized treatment. Actually the matter is not so satisfactory. In plotting h against T_c for the control stations, the points as observed in the Homer-Cotton Valley area are distributed over the paper as is shown in Figure 5 and do not lie on a smooth curve at all. This dispersion of the points has been investigated and it has been found that the principal cause of this dispersion is a

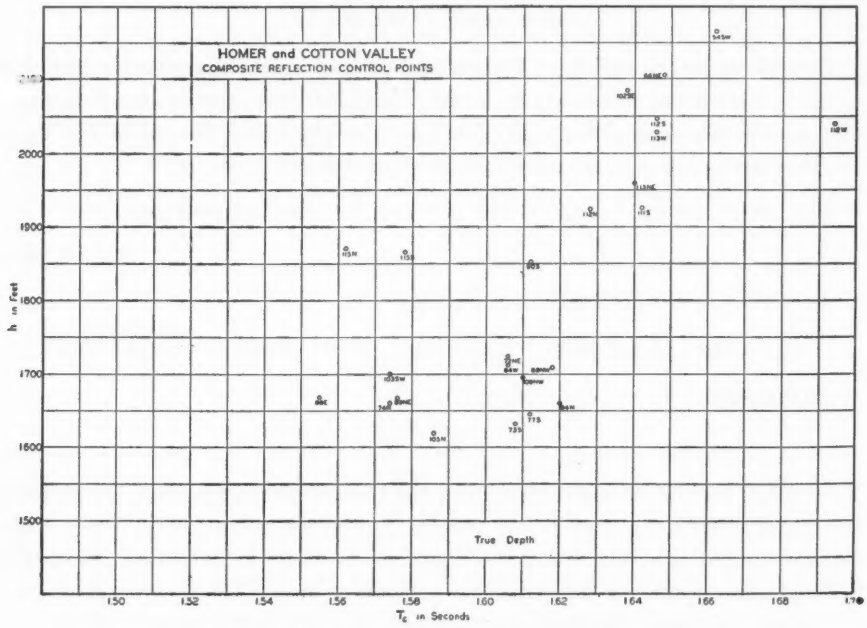

FIG. 5. Actual reflector depth vs. travel time curve at Homer and Cotton Valley (uncorrected for shear velocity variations).

variation in the velocity of the shear waves over the area being surveyed thus, this variation in shear velocity must be allowed for before any satisfactory determination of depths can be made. The values of h above are the well depths to the uppermost "hard" bed in the Nacatoch series.

These shear velocity changes may be sectional affairs, as occur, to a relatively small extent, for vertically-travelling dilatational waves, or they may lie principally in the upper layers, and hence be analogous to the well-known "weathering" variations. The data at hand have not determined the question, but the treatment given below may be shown to fit either case to a first approximation even though expressed as sectional velocity variations.

Referring again to Figure 3, it will be noticed that if h changes by a small amount, the path S_1 will change very little, but the path S_2 will change considerably. To a good first approximation we may write

$$h = v \cos \phi \, (T_c - S_1/u)$$

which says that the change in the path length S_2 is a measure of the change in depth. If u and v both were to remain constant, the function h of T_c would be linear in the limited range where S_1 may be considered as constant. However, v actually varies over the area explored. In order to allow for this variation in v, use may be made of the travel time of the direct shear wave which is shown by the path ALD of Figure 2. Due to the deeply curving nature of the path traversed by this direct shear wave, it passes through a representative part of the geologic section between the earth's free surface and the reflecting bed (and also through the "low velocity region" under the geophone). Thus, if T_s is the travel time of the direct shear disturbance and $(T_s)_0$ is the average value of T_s over the area explored we may write

$$v = v_0 \, (T_s)_0/T_s$$

where v_0 is the average value of the shear velocity over the area explored. Accordingly

$$h = v_0 \, (T_s)_0/T_s \cos \phi \, (T_c - S_1/u)$$

or

$$h = T_s/(T_s)_0 = v_0 \cos \phi \, (T_c - S_1/u)$$

or

$$\bar{h} = v_0 \cos \phi \, (T_c - S_1/u)$$

where

$$\bar{h} = h \, T_s/(T_s)_0 \, .$$

So if we correct h by the factor $T_s/(T_s)_0$ and so obtain the quantity $\bar{h}$, this $\bar{h}$ is a linear function of T_c in a limited range of variation of h.

Taking the values of h in Figure 5 and adjusting them for variations in shear velocity by forming $\bar{h}$ and then plotting $\bar{h}$ as a function of T_c, Figure 6 is obtained. It will now be observed that the points lie along a definite trend through which a representative straight line may be drawn. The points do not, of course, lie precisely on the line, the average error being of the order of 2.3 percent, with maxi-

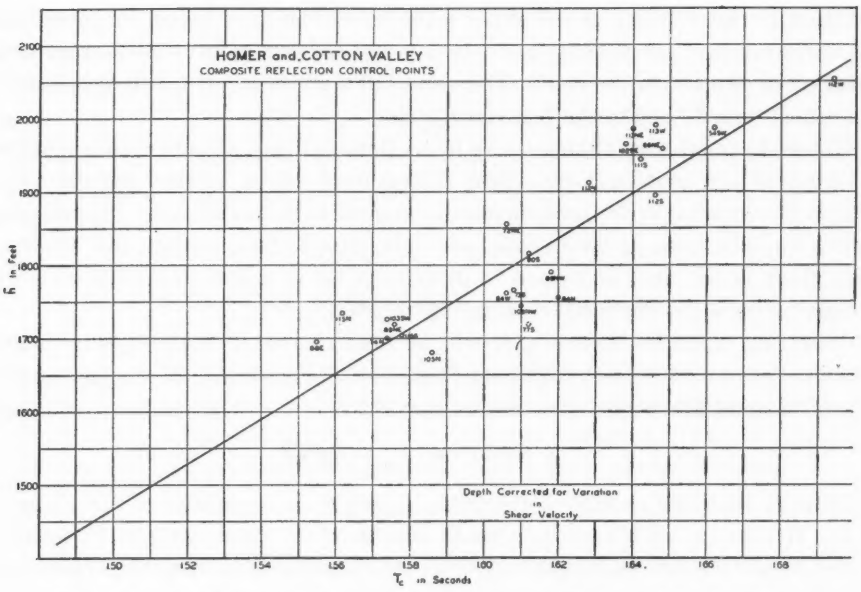

FIG. 6. Actual reflector depth vs. travel time curve at Homer and Cotton Valley (corrected for shear velocity variations).

mum error around 4.6 percent. The data given are for the Cotton Valley area where the reflector is at a depth of approximately 2,000 feet, so that the average error is of the order of 46 feet with maximum error about 92 feet. In any critical study of these data cognizance must be taken of the fact that for these control stations the reflection point does not lie precisely on the control well and that the true depth at the reflection point had in some measure to be estimated. However, by drawing an average line through the points on the $\bar{h}$, T_c diagram, depths obtained from this line might be expected to be somewhat better than those estimated at the control points. After obtaining the empirical linear graph of Figure 6 the observed values of T_c for the entire Homer-Cotton Valley area were referred

TABLE 1

HOMER AND COTTON VALLEY
Empirical Method of Interpretation

Reflection Point	Elev. Wt. Av. E_a	T_c	$\bar{h}$	T_s	$\frac{2.588}{T_s}$	$h=h\cdot\frac{2.588}{T_s}$	$E_a-h=E_r$
8-40 S	257	1.612	1812	2.475	1.0457	1895	−1836
41 N	244	1.583	1722	2.365	1.0943	1884	−1640
42 NE	261	1.622	1842	2.472	1.0469	1928	−1667
43 N	368	1.682	2028	2.522	1.0262	2081	−1713
44 SE	265	1.610	1806	2.338	1.1069	1999	−1734
45 NE	233	1.620	1837	2.431	1.0646	1956	−1723

to this graph and values of $\bar{h}$ obtained. The true value of h was obtained by multiplying $\bar{h}$ by the ratio $(T_s)_0/T_s$.

The type of tabulation of data used for this computation is shown in Table 1.

After obtaining the elevation of the reflector, E_r, from these calculations, the contour map, Figure 12, was prepared. The contours are drawn with reference to indicated well depths as well as to reflection depths.

THE RATIONAL METHOD OF INTERPRETATION

In the course of the survey of the Homer and Cotton Valley area, refraction profiles made with both horizontal and vertical component geophones were run in two regions having a reasonably flat subsurface as best could be judged from known subsurface data. One of these regions was along the profile 8-40 S and its reversal 8-41 N; the other was along the profile 8-106 S and its reversal 8-107 N. From these profiles the dilatational refraction data first were studied and from these observations it was determined that the first refracting surface lay at a depth of 1,809 feet below the surface of the ground. It was found also that the velocity, u, of dilatational waves in the region above this refraction surface, was 6,500 feet per second, and that the velocity of dilatational waves in the region below this first refraction surface was 10,300 feet per second. A graphical chart was next prepared, similar to Figure 1, showing the subsurface geometry, including the ray path of the composite reflection. The distance X was set at 5,500 feet and h at 1,809 feet. The value of T_c, the travel time of the composite reflection in the region between 8-40 S and 8-41 N was known to be 1.600 secs. Accordingly a number of positions of the reflection point B were tried, the lengths S_1 and S_2 scaled from the chart and the values substituted into the equation $S_1/6{,}500 + S_2/v = 1.600$. Thus, the value of v necessary to give the composite reflection time $T_c = 1.600$ could be represented as a function of the position of the point B. Only one of these values, however, satisfies the condition $\sin\theta/6{,}500 = \sin\phi/v$. Since $\sin\theta$ and $\sin\phi$ also could be determined from the chart, a second value of v satisfying this second condition could be obtained for each position of B. Thus, by a method of successive approximation the position of B was determined at which the two equations gave the same value of v. Thus, the value of v was determined as 2,340 feet per second as the sectional velocity of the shear waves. This value is in accordance with velocities obtained from the time-distance curve of the direct shear disturbance and therefore was regarded as the true sectional shear velocity at that location.

Thus, the values of the velocities were

$$u = 6{,}500 \text{ ft/sec} \quad \text{and} \quad v = 2{,}340 \text{ ft/sec.}$$

The scaled length of S_1 was found to be 5,096 feet, so that the time required by the dilatational part of the path was

$$t_1 = 5{,}096/6{,}500 = 0.784 \text{ sec.}$$

If t_2 is the time required by the shear part of the path

$$t_2 = T_c - 0.784.$$

Now

$$h = 2{,}340 \cdot t_2 \cdot \cos \phi.$$

The value obtained for $\cos \phi$ was 0.9256 so that the equation

$$h = 2{,}340 \cos \phi (T_c - 0.784)$$

becomes

$$h = 2{,}166(T_c - 0.784).$$

Thus, were the shear velocity to remain constant at 2,340 ft. per second, the depths could be determined from this equation. However, as explained ealier in this report, the velocity at an arbitrary station is given by

$$v = v_0 (T_s)_0 / T_s$$

where $(T_s)_0$ is the value of the travel time T_s of the direct shear disturbance at the place where the shear velocity is known to be V_0. The value of $(T_s)_0$ in the neighborhood of 8-40-S and 8-41-N is 2.410 seconds, so that

$$v = 2{,}460 \cdot (2.410/T_s) \cdot$$

And so finally

$$h = 2{,}166(T_c - .784) \cdot (2.410/T_s) \cdot$$

Depths then were calculated from this formula. An excerpt from the tabulated calculations is given in Table 2.

TABLE 2

HOMER AND COTTON VALLEY
Rational Method of Interpretation

Reflection Point	Elev. Wt. Av.	T_c	T_s	$(T_c - .784)$	$h_1 = 2166 (T_c - .784)$	$\frac{2.410}{T_s}$	$h = h_1 \cdot \frac{2.410}{T_s}$	$E_a - (h + 202) = E_r$
8-40 S	257	1.612	2.475	.828	1793	.9737	1746	−1691
41 N	244	1.583	2.365	.799	1731	1.0190	1764	−1722
42 NE	261	1.622	2.472	.838	1815	.9749	1769	−1710
43 N	368	1.682	2.522	.898	1945	.9556	1859	−1693
44 SE	265	1.610	2.338	.826	1789	1.0308	1844	−1781
45 NE	233	1.620	2.431	.836	1811	.9914	1795	−1764

After calculating h for all stations, the degree of misfit with known subsurface data was studied and it was seen that on the average these calculations placed the reflector too high by 202 feet, relative to the uppermost hard bed of the Nacatoch series. Accordingly, the elevation of the reflector was determined by

$$E_r = E_a - (h + 202).$$

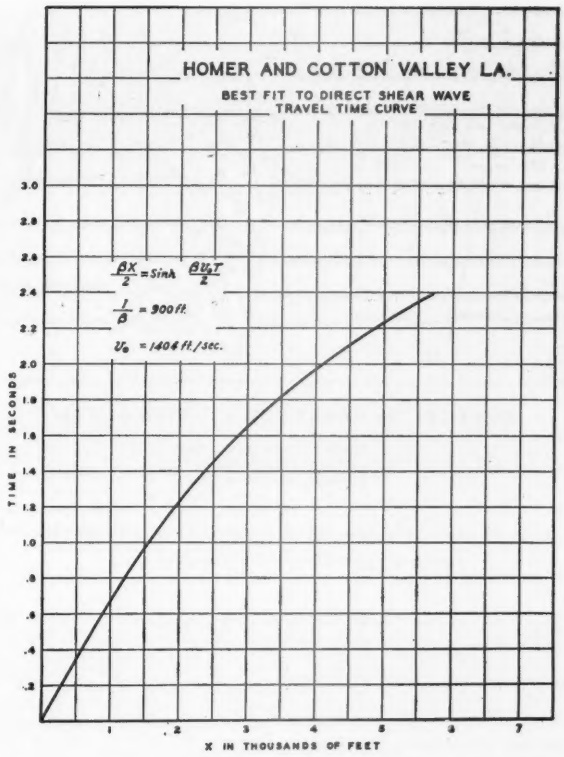
HOMER AND COTTON VALLEY LA.
BEST FIT TO DIRECT SHEAR WAVE
TRAVEL TIME CURVE
$\frac{\beta X}{2} = \sinh \frac{\beta V_0 T}{2}$
$\frac{1}{\beta} = 900$ ft.
$V_0 = 1404$ ft./sec.
TIME IN SECONDS
X IN THOUSANDS OF FEET

FIG. 7. Best fit to travel time vs. distance data with circular ray paths for primary shear disturbance.

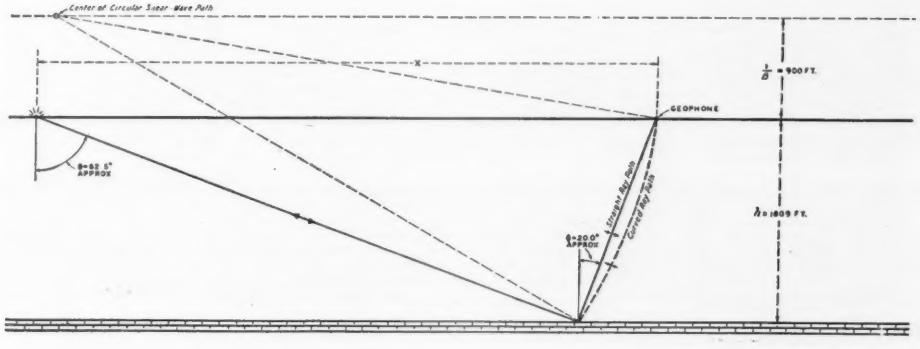

FIG. 8. Showing curved ray path in comparison with straight ray path, for shear part of composite reflection.

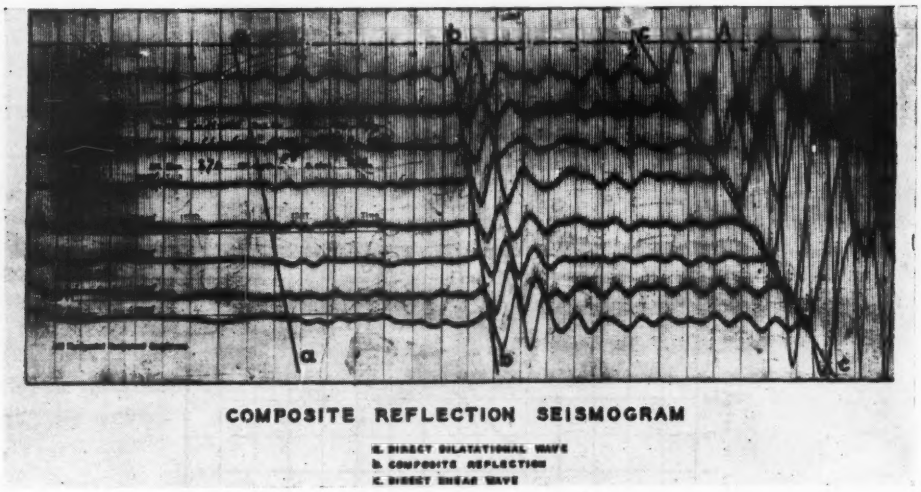

FIG. 9. Composite reflection seismograms—Hattiesburg, Mississippi, with all geophones of horizontal type.

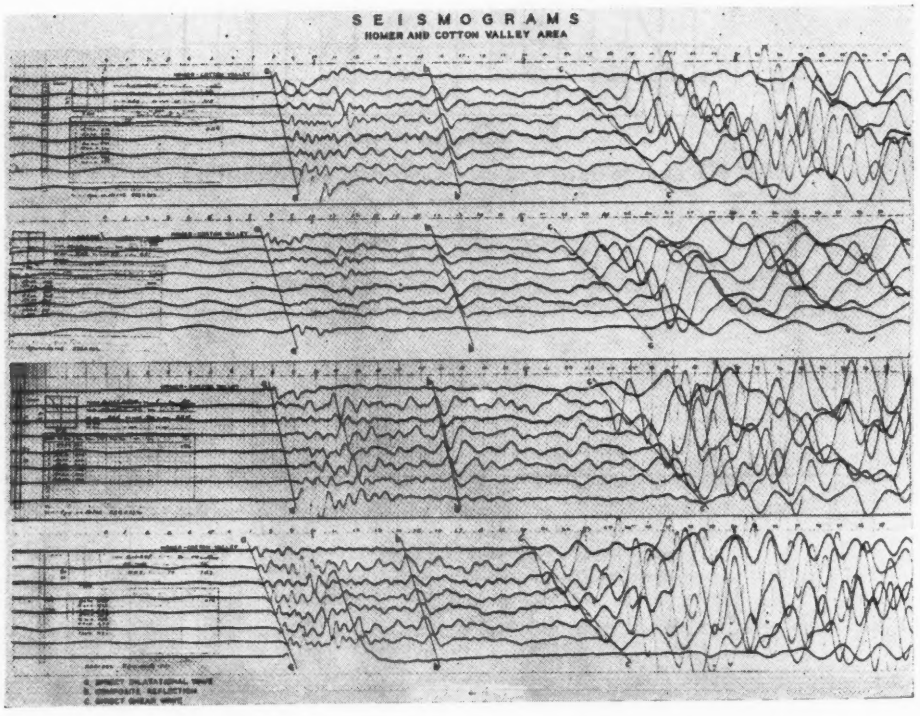

FIG. 10. Composite reflection seismograms—Homer and Cotton Valley area near Minden, Louisiana. Traces 2 to 7 horizontal, in-line geophones. Traces 1 and 8 vertical component geophones.

These elevations are shown on the contoured map, Figure 13, where the contour interval is 50 feet. As in Figure 12, well depths as well as reflection points are used.

Note on the Path of the Shear Wave—In Figure 7 there is shown a curve which represents the best fit to the travel time data of the direct shear wave. From this curve it will be seen that the centers of the circular ray paths lie at a height of 900 feet above the earth's purpose. In Figure 8 the ray paths of the composite reflection are shown for two interpretations of the shear part of the travel path

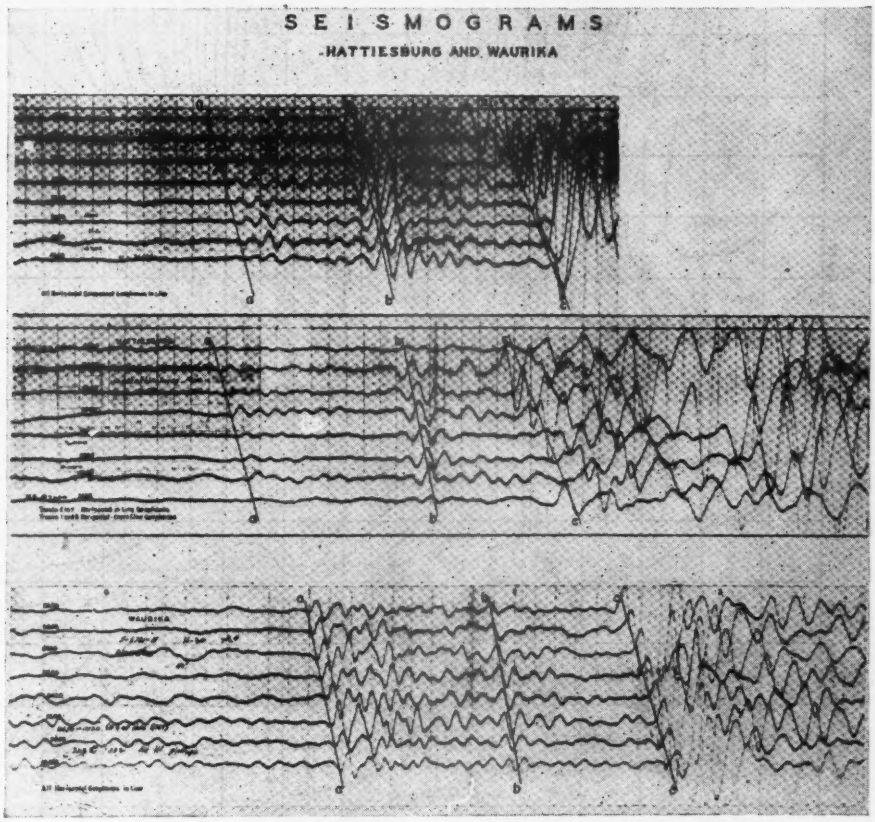

FIG. 11. Composite reflection seismograms from Hattiesburgh, Mississippi, and Waurika, Oklahoma.

the solid line representing a straight ray path interpretation and the dotted line the curved ray path interpretation. The purpose of the figure is to show that the straight ray path interpretation is justified due to the very slight difference between the circular arc and its chord.

Discussion of Results—Upon comparing Figures 12 and 13 wherein the reflector elevations were computed by different methods, it will be seen that the

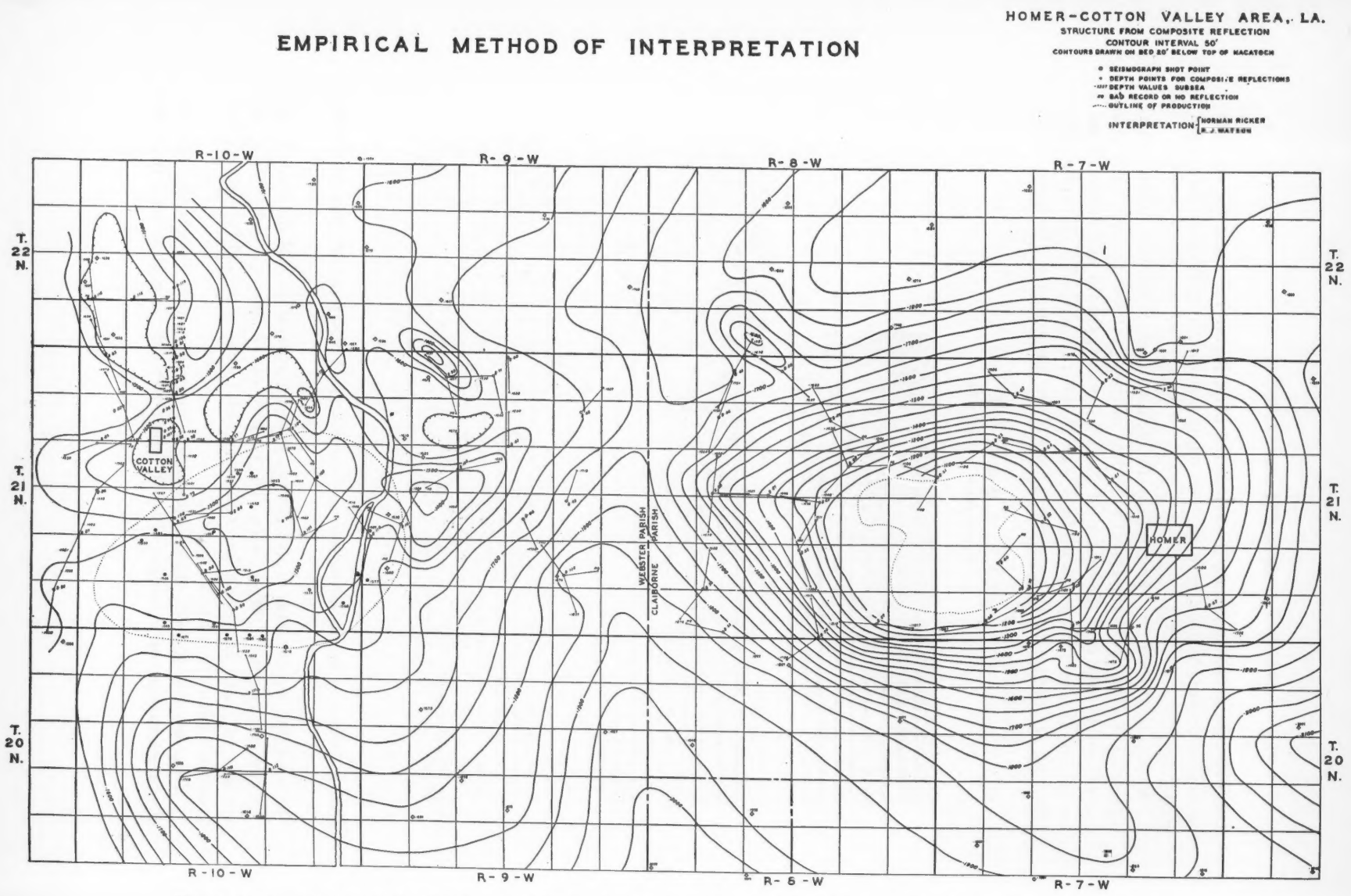

FIG. 12. Contours drawn on bed 20 ft. below top of Nacatoch at Homer and Cotton Valley, Louisiana. Empirical method of interpretation.

FIG. 12. Contours drawn on bed 20 ft. below top of Nacatoch at Homer and Cotton Valley, Louisiana. Empirical method of interpretation.

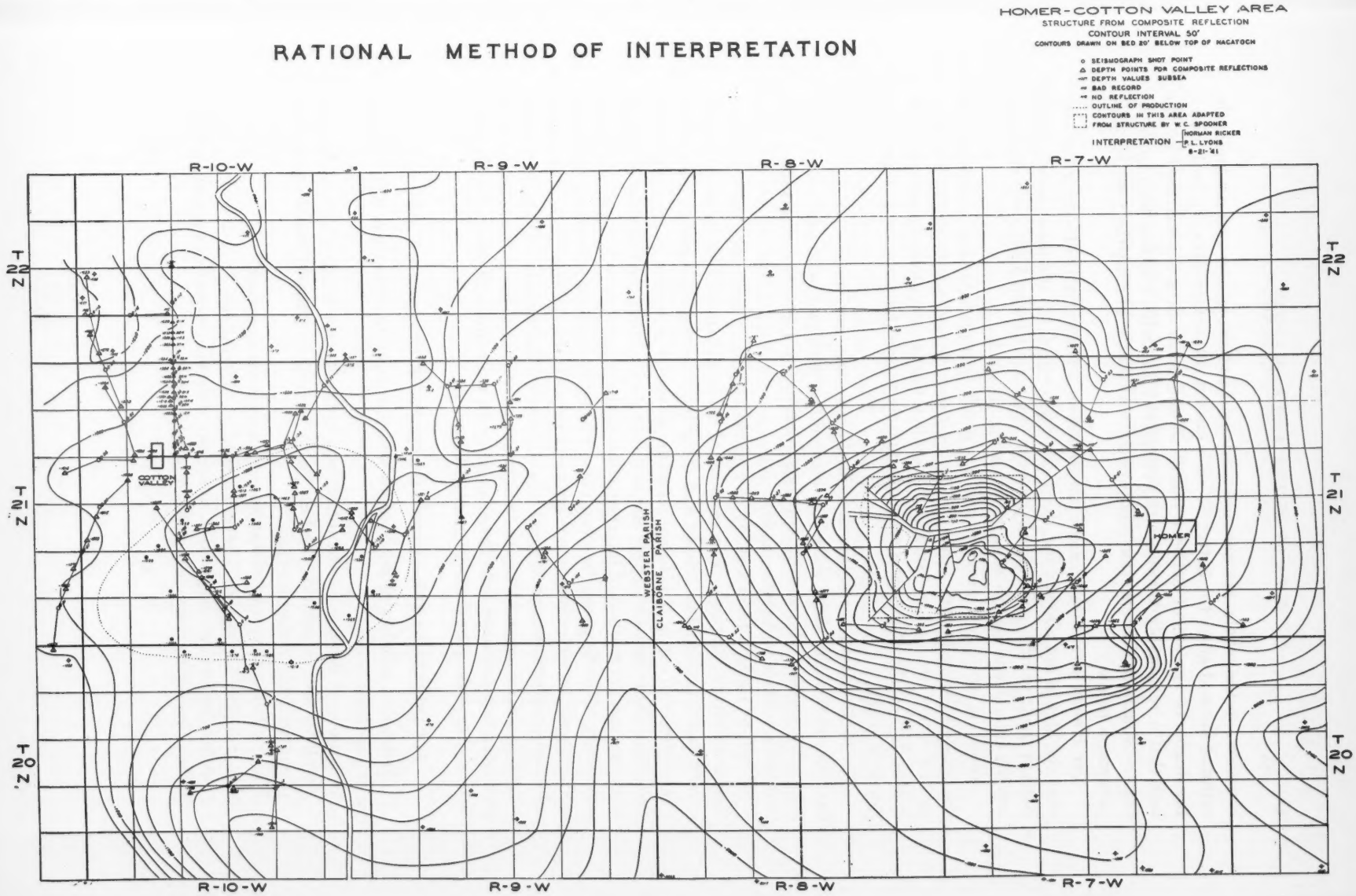

FIG. 13. Contours drawn on bed 20 ft. below top of Nacatoch at Homer and Cotton Valley, Louisiana. Rational method of interpretation.

contours, on the whole, are not substantially different. Of the two methods, the rational method gives the better fit with known subsurface data. In both cases, the degree of agreement between reflection and other data is illustrated by the fact that a reasonably smooth and geologically probable contour map could be drawn using both the reflection points and the available well depths. (See also last paragraph below.)

The Homer structure is easily revealed even if the variation in shear velocity over the area is not allowed for, due to its great relief. On the other hand, variations in shear velocity entirely obscure the low relief Cotton Valley structure unless the corrections for this velocity variation are made.

Referring again to Figures 12 and 13, it will be seen that the "roughness" of the points relative to each other and to their own contours is generally less than 50 feet. They are not as "smooth," in other words, as conventional reflection depths, but on the other hand seem adequately precise for structures of any considerable relief.

The *shear velocity* correction described above was not wholly satisfactory in that the onset of the shear wave was often difficult to pick with precision. However, with some study, and by applying consistency and other criteria, it is felt that fairly reliable picks were made.

It will be noticed from a study of Figures 12 and 13 that over the top of the Homer structure composite reflections could not be obtained. This localized region is very badly faulted and broken and the ground seems to be rather loose here. The contours on top of the Homer structure as shown in Figure 13 are taken from subsurface data (Spooner, 1929) and it will be noticed that the contours obtained from the rational method of interpretation of the composite reflection data tie in very nicely with the subsurface contours. In Figure 12 these subsurface contours on the top of the structure are not drawn in because the tie-in with the composite reflection contours are not as good when the empirical method of interpretation is used. It will be noticed that the fault to the northeast of the Homer structure as delineated by composite reflections, aligns itself with the fault shown by the subsurface data within the dotted square of Figure 13.

ADVANTAGES OF THE COMPOSITE REFLECTION PROSPECTING METHOD

There are a number of advantages which composite reflections offer. These are enumerated below:

a. In regions of unconsolidated formations the reflection is often outstanding in simplicity and prominence, and the "pick" is usually unquestionable, provided of course that a reflector exists.
b. Hole-to-hole and spread-to-spread correlations are excellent.
c. The composite reflection is never masked by "ground roll."
d. The low frequencies involved in composite reflection operations greatly reduce difficulties due to 60-cycle high line disturbances.

LIMITATIONS OF THE METHOD

a. In the areas visited, only the first hard bed has been workable.
b. The great distance from shot to geophone involves more surveying.
c. The depth determinations are slightly less precise than with conventional reflections.

POSSIBLE UTILITY OF COMPOSITE REFLECTIONS

While to the knowledge of the authors there has so far been little commercial utilization of this method, there still seems to be a possibility that its use would be advantageous in those areas peculiarly suited to its requirements. As indicated above, these are areas where useful information is to be gained from determination of the thickness of a relatively unconsolidated section overlying harder beds. In such cases it is felt that the ease of correlation observed in tests to date, and the consequent reduction of the number of locations required, might make the method competitive with conventional reflection and refraction techniques.

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SEISMIC WAVE PROPAGATION*

D. H. CLEWELL† AND R. F. SIMON†

ABSTRACT

Speculations are made regarding the significance of the well-known observation that seismic reflection energy is usually in the frequency range of from 20 to 100 cycles per second. The general absence of reflected energy below 20 cps is attributed to the fact that the wavelengths of seismic waves in this frequency range are becoming large compared to the thicknesses of reflecting beds; accordingly, the reflection coefficients are low with the results that the geologic section appears more or less homogeneous, the low frequency energy is unweakened by reflections, is transmitted efficiently, and can only return to the surface by refraction.

As the frequency is increased the wavelengths become comparable to the vertical discontinuities represented by stratification and more efficient reflection takes place with the result that reflected energy is returned and detected at the surface. At still higher frequencies the wavelengths become comparable to small inhomogeneities distributed at random throughout the geologic section and the energy is therefore diffused and scattered to such an extent that transmission into the earth is limited. This weakening of the main wave front by scattering, plus the weakening by absorption processes involving viscous and solid friction, constitute an effective cutting off of high frequency transmission. The high frequency scattered energy diffuses back to the surface and appears on the seismogram as "hash," unless eliminated by filters, or is absorbed before it reaches the surface.

Such a speculative picture of seismic energy propagation accounts qualitatively for (1) the continuous reception of random energy that is always superimposed upon the reflection energy, (2) the tendency for deep reflections to be of lower frequency than shallow reflections, and (3) the fact that theoretical considerations of absorption do not always account for known attenuation of high frequency seismic energy.

INTRODUCTION

It is generally accepted that the energy associated with the reflection of elastic wave pulses from geologic interfaces varying in depth of from a few thousand feet to well over ten thousand feet lies in a band of frequencies extending roughly from 20 to 100 cycles per second. It is quite important that the reasons for the existence of such a band be understood. If this band width represents an inherent limitation in seismic exploration, it should be known so that further development work can then ignore frequencies substantially outside this band. However, if there *are* possibilities of working outside this band, it is obligatory that these possibilities be evaluated.

It has been recognized by many that an increase in the useful resolving power of the seismograph would be profitable because it would yield more detailed information about the subsurface. For example, an increased resolving power would enable one to follow a thinning bed more nearly to the actual pinch-out than is now possible. Also, more information about stratigraphic traps in general would become available. Resolving power may be defined as the shortest time interval that can exist between the arrivals of two reflections at the geophone and still permit the recognition of two distinct arrivals. Generally, it is a function of the

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"build-up" time of the arriving transients, since it is a necessary minimum condition that the first arrival approximately level off at its maximum amplitude before the second transient starts to build up.

This "build-up" time is controlled by two factors: *first*, the sharpness of the original pulse generated at the shot point,‡ and *second*, the width of the band of frequencies passed by the earth and the recording system. The "build-up" time is inversely proportional to the band width, and for a band of frequencies 50 cycles per second wide this time is of the order of 0.01 second. At velocities of 10,000 ft/sec this would be equivalent to saying that the reflections from two interfaces separated by a distance of less than 50 feet could not be distinguished from one another.

It is the purpose of this paper to discuss general reasons why the earth appears as a band pass filter to reflected energy. But it is concluded, however, that present day use of the seismograph is not too seriously limited in resolving power by this band pass characteristic. Nothing essentially new in the way of factual data will be presented and the danger of drawing generalizations is well appreciated by the authors.

FILTER CHARACTERISTICS OF SEISMIC TRAVEL PATHS

It has often been stated that the earth is a *low* pass filter to seismic energy, rather than a band pass filter. A consideration of absorption mechanisms lends substantial support to such a statement. Absorption due to the viscous nature of earth materials will produce a logarithmic attenuation proportional to the square of the frequency. However, Born (1941), has shown that this mechanism is not important below about 150 cycles per second. Absorption by solid friction will also give rise to logarithmic attenuation, which, in this case, is directly proportional to the frequency. Born's work (1941), indicates that this mechanism is in a fair accord with the observed attenuation, although Howell's (1940), investigations on the propagation of sine waves over short distances casts some doubt on the assumption that this is always true.

Any logarithmic absorption which increases with frequency will result in a lowering of the frequencies composing any transient as the distance of propagation increases. Everyone is familiar with the fact that the transients produced by earthquakes are predominantly of very low frequencies after they have traveled distances of the order of hundreds or thousands of miles. It is also true that the transients associated with refraction shooting are of considerably lower frequency than the transients associated with reflection shooting. Here again, the lower frequency is generally explained by the longer travel paths involved in refraction shooting.

In reflection work frequencies below 25 cycles are rarely used. One reason for not using frequencies appreciably below about 25 cycles per second is the exist-

‡ Cf. p. 59. The important pulse is not the one at the shot-hole, but the one at the boundary of the zone of non-elastic propagation.

ence of low frequency surface waves or "ground roll" which are often of such amplitude that they completely mask reflections, unless eliminated from the seismogram.

However, it is the first objective of this discussion to call attention to another phenomenon which very probably limits the use of low frequency energy in reflection work; namely, the fact that if the wave-length of seismic energy is large compared to the thickness of the stratigraphic units, the reflection coefficients at the bed interfaces become very small. In other words, for low frequencies, the stratigraphy is unimportant, the entire section appears more or less homogeneous, and energy is returned to the surface only by refraction. This is a quite general consideration, since it is well recognized that it is difficult to detect any object that is small compared to the wavelength of the radiation used in probing for the object. For example, the examination of an object under a microscope is impossible if the object is small compared to the wavelength of light.

For thick beds this consideration is of no importance, but when a maximum of resolving power is required to delineate thin beds it may very well be a limiting factor. The foregoing may be summarized by writing the following simplified equation:

$$A_r = \frac{A_0}{2X} f_1\left(\frac{d}{\lambda}\right)\left[\exp\ -2Xf_2\left(\frac{k}{\lambda}\right)\right].$$

Where:

A_r = Amplitude of a reflection frequency n
A_0 = Initial amplitude of the frequency n
V = Velocity
$\lambda = V/n$ = wavelength
X = Distance to reflecting interface
d = Bed thickness

The function $f_1(d/\lambda)$ represents the reflection coefficient, and has the property of being independent of the wavelength, λ, when λ is small compared to d, the bed thickness, and becomes inversely proportional to λ at large wavelengths. The basic reason for a reduction in the reflection coefficient of thin beds is the interference of the two reflections from the top and bottom of the bed. Thus, it is easy to see that when d and λ are of comparable magnitude, the reflection coefficient varies in a complicated matter, as the interference varies from destructive to constructive interference.

For the general purposes of this discussion, it is not necessary to discuss these complications except to point out by way of example that if the acoustic resistance of the bed is the geometric mean of that of the media above and below it, and the bed is an odd number of quarter wavelengths thick, the reflection coefficient is zero (Stewart and Lindsay, 1930). For beds thinner than a quarter wavelength, the reflection coefficient is approximately proportional to sin $2\pi d/\lambda$.

However, a qualitative picture of the general behavior of the reflection coefficient at long wavelengths can be obtained most simply by assuming:

$$f_1(d/\lambda) = d/d + \lambda/10.$$

This function ignores the contrast in acoustic resistance, and has been selected mainly to show the probable dependence of the reflection coefficient on wavelength when the latter is large. At small wavelengths, of the order of $4d$ and smaller, the above function is practically independent of frequency. This is only true as far as general trends are concerned. In any actual case the reflection coefficient will go through maxima and minima as the ratio, d/λ, is varied in the region where d and λ are of the same order of magnitude.

The function $f_2(k/\lambda)$ represents the attenuation constant, and, as pointed out previously, is simply proportional to $1/\lambda$ for solid friction absorption and to $1/\lambda^2$ for viscous absorption. The former is assumed here.

Inspection of this admittedly oversimplified equation for A_r gives a qualitative picture of how the earth, as far as reflection shooting is concerned, may act as a band pass filter rather than as a low pass filter. The reflection amplitude A_r is zero at low frequency and at high frequency, and must then have a maximum at some intermediate frequency. A plot of A_r as a function of frequency, assuming that f_1 is

$$d/d + \frac{\lambda}{10}$$

and that f_2 is k/λ, solid friction, is shown in Figure 1. The assumed value of k is 0.02, and was taken from Born's paper (1941).

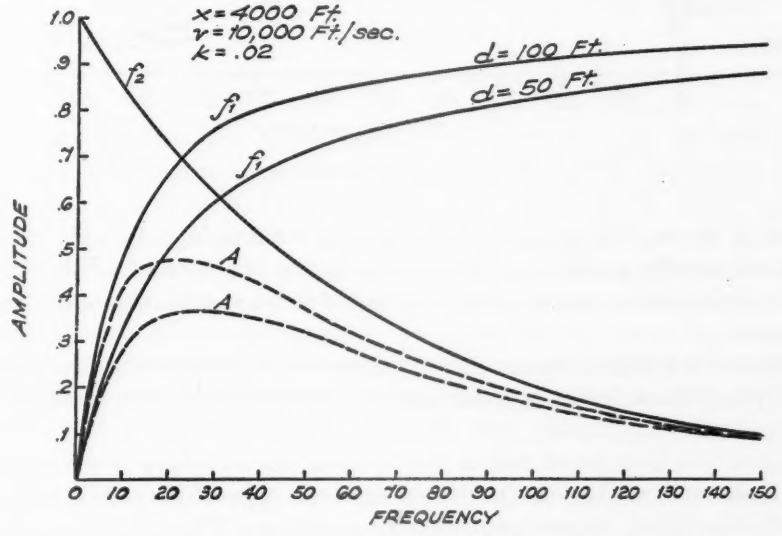

FIG. 1. Frequency characteristics of the earth.

The solid curves are for f_1 and the exponential function individually and the dashed curve is the resultant response obtained by multiplying them together. Again it should be emphasized that f_1 has in reality a number of maxima and minima in the higher frequencies.

Under the assumed conditions, it is seen that the reflection path in the case of a reflection from a 100 foot thick bed transmits a band of frequencies peaked at approximately 20 cps, while the band reflected from a 50 foot thick bed is

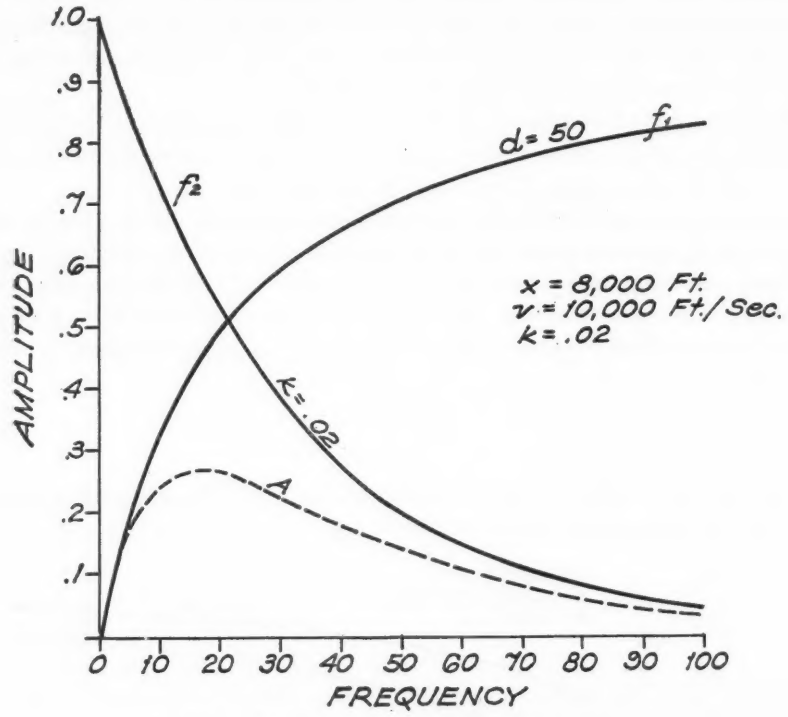

FIG. 2. Frequency characteristics of the earth.

peaked at 30 cps. The graphs refer to ground amplitude, and, when using conventional velocity geophones, the peak frequency of the band will be shifted to higher values, since all ordinates of the dotted curve should then be multipled by frequency.

Figure 2 is a plot of the same type, where now a 50 foot thick bed is assumed at a depth of 8,000 feet. The usual shift to lower frequency with increased depth can be noted.

Figure 3 is a replot of two of the previous curves where now the ordinates have been multiplied by frequency to show the type of frequency response expected when using conventional velocity geophones. The velocity geophone accentuates the low frequency cut-off and here the peak frequencies have been

moved from about 18 cps to 35 cps for the 8,000 foot reflection and from about 20 cps to 70 cps for the 4,000 foot reflection.

So far it has been assumed that the high frequency cut-off is due to absorption by solid friction mechanisms. However, it should be remembered that the earth's crust is far from homogeneous. The stratification, which one endeavors to map with the reflection seismograph, is one form of inhomogeneity. In addition to this, there are numerous smaller irregularities which are encountered in both horizontal

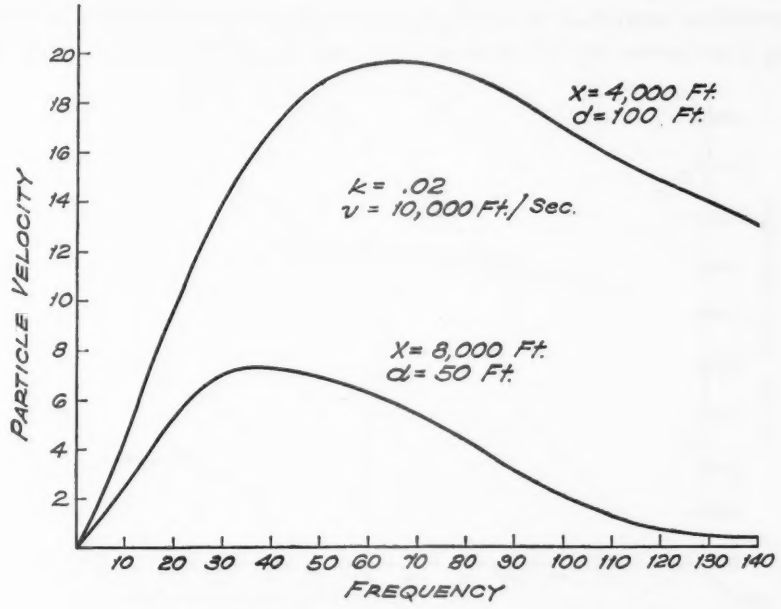

FIG. 3. Frequency characteristics of the earth.

and vertical directions. These irregularities or inhomogeneities will give rise to scattering or diffusion of the seismic wave energy. The intensity of scattering is a function of wavelength and the size of the irregularity. If the latter is smaller than the wavelength, the scattered amplitude, borrowing from our knowledge of the Rayleigh scattering of light, is proportional to d^3/λ^2, where now d is the diameter of the inhomogeneity. For larger inhomogeneities, the scattering is proportional to $1/\lambda$, and for still larger inhomogeneities, the scattering is reduced to regular reflection and is independent of the wavelength. Thus, it is evident that thin beds, other than the one being mapped, will also affect the frequency characteristics of the seismic travel path by preferentially diffusing the high frequency energy out of the main wave front.

This weakening of the seismic energy will have the same effect as solid friction absorption, since it is also a function of $1/\lambda$. Likewise, the d^3/λ^2 scattering by the smaller inhomogeneities will weaken the forward traveling energy in the same

manner as viscous absorption. Hence, as far as the reduction in amplitude of a reflection on a seismogram is concerned, scattering is indistinguishable from absorption. This tacitly assumes, probably correctly, a large number of scatterers. However, scattering does add an additional difficulty because it contributes to the diffuse background of random energy on the seismogram, and tends to mask the coherent reflected wave. The fact that a seismic galvanometer trace never becomes "quiet" in the interval of time between reflections may be due in part to scattering effects.

The relative magnitude of scattering and absorption mechanisms in reflection shooting is unknown, but it is believed that more quantitative knowledge of their

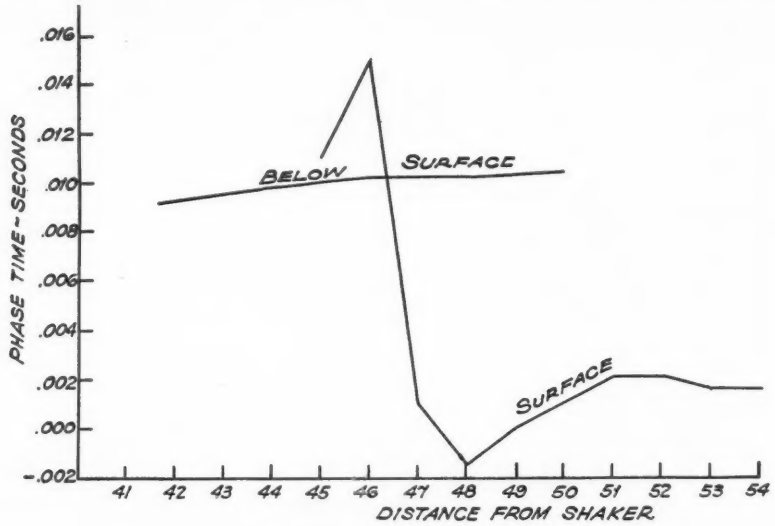

FIG. 4. Steady state phase response.

behavior would be helpful in understanding and improving the seismic art. For example, it is very likely that each stratigraphic unit has a characteristic scattering and absorption coefficient. Speculation on this point also indicates that the greatest amount of scattering may occur in the weathered or other near surface layers. This of course is unfortunate since scattering near the surface will be most effective in adding to unwanted background disturbances on seismograms.

That small inhomogeneities exist can be illustrated by some measurements that have been made in the caliche area of southwest Texas. A study of the steady state response of the surface caliche was being made with a sinusoidal ground driver, consisting of an eccentrically mounted weight on an otherwise balanced flywheel driven at various speeds. The amplitude and phase of the sine wave motion of the ground was measured as a function of distance from the ground driver, and compared with the phase and amplitude of a reference geophone placed close to the driver. At a distance of about 44 feet from the driver at one

particular set up the phase of a 48 cycle signal, which had been changing more or less uniformly with distance, suddenly changed as much as 180 degrees within a few feet, and the amplitude went through a distinct minimum.

Figure 4 is a plot of the data in the vicinity of this singularity. The ordinates are the phases of the 48 cycle sine wave motion measured in time rather than

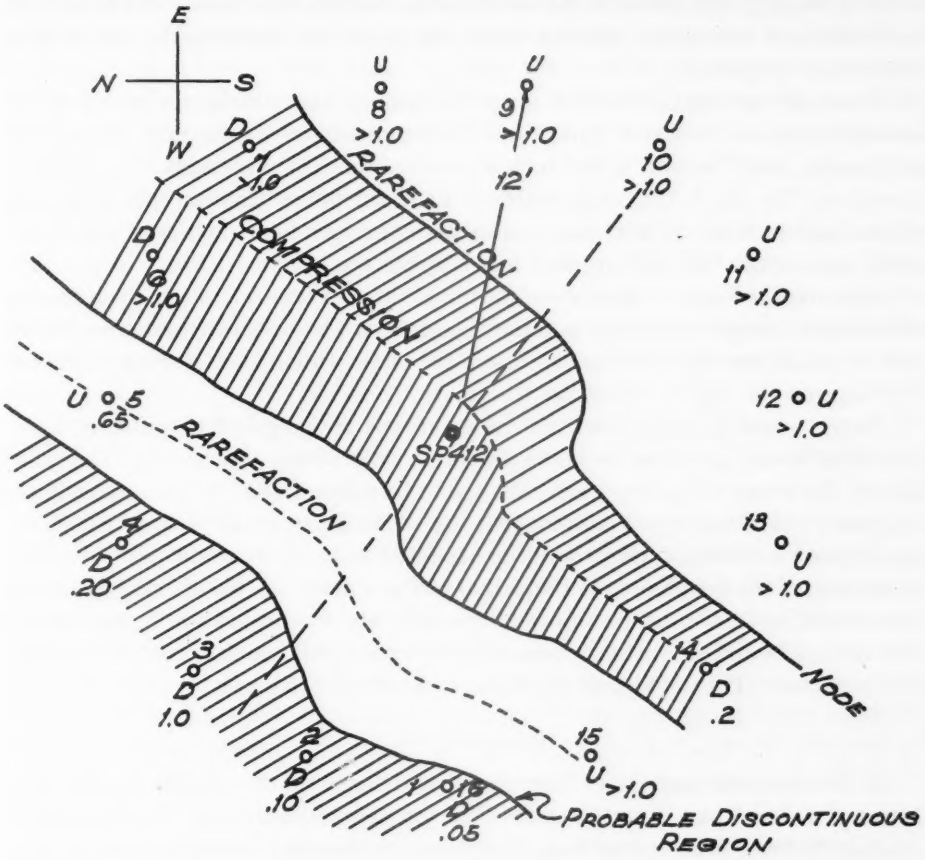

FIG. 5. Vertical wave motion resulting from arrival of initial uphole energy in area of surface singularities.

degrees. The "below surface" curve represents data obtained from geophones placed 15 feet below the surface, while the "surface" curve depicts the anomalous data mentioned above. Both the surface and subsurface geophones were in a solid caliche of the order of 50 feet in thickness. The "below surface" curve shows a gradual change in phase and is about what one would expect in a homogeneous medium. The surface curve is somewhat in accord with what would be expected if there existed in the caliche nearby a cavity filled with perhaps a mass of more caliche, but elastically connected to the walls of the cavity so that the inner mass

would resonate at around 48 cycles per second. As the frequency goes through the point of resonance, large phase shifts and sudden changes in amplitude would be expected. This anomalous area was found to have a horizontal extension of about 15 feet, and a vertical extension of about 10 feet. There was no visible evidence of this singularity. It was delineated only by the procedure mentioned above; namely, placing a geophone at different points, both on the surface and in shallow boreholes and noting the position where the phase changed rapidly either with distance or frequency.

It was interesting to note that in another similar area nearby the inhomogeneous character of the near surface was further emphasized by the fact that uphole geophones placed within a few feet of one another would "break" in opposite directions. To check this observation a little further a circular spread of geophones was laid out on a 12 foot radius with the shot point at the center. Some of the geophones "broke" up, and some down.

The map in Figure 5 shows the pattern that was found and clearly indicates the sudden changes in the character of the surface. The shaded area delineates the area in which the first motion of the surface of the caliche was *down* and the unshaded area the region where the first motion was *up*.

There would appear to be little question that an irregularity of the type just described would give rise to scattering of seismic energy. Because of the small size of the irregularity, the scattering would be proportional to the square of the frequency. In areas where inhomogeneous strata exist at or near the surface, interference from scattering would be expected to be at its worst because of the proximity of the geophones to the origin of the scattering. Additionally, the surface would scatter or diffuse not only the ordinary compressional waves but also the various boundary waves generated by the shot and which travel horizontally in the surface. This, of course, is often found in caliche areas.

CONCLUSIONS

It is concluded that the evidence is fairly definite that the earth has the properties of a band pass filter for reflection frequencies, and that the frequencies transmitted and reflected with greatest ease are the ones normally used in prospecting.

The general absence of reflected energy below 20 cps is attributed to the fact that the wavelengths of seismic waves in this frequency range are large compared to the thicknesses of reflecting beds; accordingly, the reflection coefficients are low with the result that the geologic section appears more or less homogeneous, the low frequency energy is unweakened by reflections, is transmitted efficiently and can only return to the surface by refraction. As the frequency is increased the wavelengths become comparable to the vertical discontinuities represented by stratification and more efficient reflection takes place with the result that reflected energy is returned and detected at the surface. At still higher frequencies absorp-

tion and scattering by small irregularities constitute an effective "cut-off" of transmission.

It does not appear reasonable to expect that frequencies substantially outside the pass band can be used. Nevertheless, the slope of the frequency response curve at the cut-off points is not infinite, and it is possible that ingenious arrangements may permit a widening of the useful band, and, hence, the obtaining of a maximum of resolving power. From any particular locality to another the pass band of the earth may vary considerably. The frequency characteristics that have been shown are very generalized, and a measurement of the actual frequency response of the earth at any point would doubtless show many irregularities superimposed on such a general trend. The frequency characteristics discussed here are merely suggestive of what that general trend might be.

It is quite evident that the selective filters usually used in the recording equipment preclude full utilization of the pass band of the earth. The use of such filters is necessary to effect a workable compromise between the rejection of random background energy and maximum response to the reflection signal. The desirability of rejecting disturbing energy by means other than narrow band filters is evident.

As mentioned in the beginning, the width of the earth pass band is only one factor in obtaining short build-up times and high resolving power. Another factor, which we believe to be of far greater importance, is the sharpness of the original pulse generated at the shot point. When the powder charge in the shot hole explodes, the displacements in the immediate vicinity of the explosion are very large and exceed the range of linear elasticity of earth materials. A proportionality between stress and strain does not exist. In many cases fracturing and permanent sets result which account for a large dissipation of energy. As the energy moves out from the explosion, the amplitude decreases and finally comes within the range of linear elasticity. From this point on the dissipation is much less and efficient propagation of the wave ensues. The form of the transient at this point is the real form of the input signal to be considered in propagation and reflection phenomena.

The work published by Sharpe (1942), as well as our observations, show very definitely that within a short distance, of the order of from 25 to 100 feet, the shot energy has been already spread out in time to the extent that it appears as a train of waves having durations of from several hundredths to as much as a tenth of a second or more. The build-up time of such a transient varies over wide limits, depending on its complexity. This is the transient that is reflected from successive interfaces, and because of its length, it is not hard to visualize the difficulties associated with the overlapping of two closely spaced reflections. It is concluded that the more profitable advances in the improvement of the resolving power of the reflection seismograph will result from techniques which shorten and simplify the input signal, rather than from efforts to widen the band of useable frequen-

cies. The elimination of the non-linear displacements in the vicinity of the shot point appears to be an obvious approach.

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SOME CONSIDERATIONS OF THE MECHANISM OF THE GENERATION OF SEISMIC WAVES BY EXPLOSIVES*

GEORGE MORRIS†‡

ABSTRACT

The mechanism whereby an elastic pulse is generated in the ground due to the detonation of an explosive charge is discussed. Initially the pressure in the borehole is very high, of the order of several hundred tons per square inch. The sudden impact of this on the walls of the borehole causes a shock wave in the ground, the intensity of which is very much greater than the ground can bear, so that the wave rapidly loses energy in fracturing the ground, and degenerates into an elastic pulse at a distance defined as the critical radius. This elastic pulse is transmitted sensibly unchanged through the ground. The ground vibration detected by a geophone is the synthesis of this pulse modified by reflections and refractions at the interfaces of the geological formation of the site, spread out in time according to the paths along which the components have travelled. Although adequate quantitative information is lacking, an attempt is made to evaluate such a pulse at various stages of its career in order that the physical magnitudes involved may be appreciated.

INTRODUCTION

Explosives are almost universally used for generating the earth waves employed in the seismic methods of prospecting, yet very little seems to have been published about the process whereby the violent action of an explosion produces an elastic wave train in the earth.

While present knowledge appears to be only capable of giving a general description of the mechanism involved, it is thought that such a picture, uncertain though it is quantitatively, may help in the improved use of explosives in prospecting and may also serve to indicate the directions in which experimental studies of the mechanism may be directed most profitably.

ACKNOWLEDGMENTS

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GENERAL DESCRIPTION

For the sake of simplicity we shall first examine the action of a spherical charge of explosive initiated at its center and buried in an infinite isotropic medium. Since the detonation wave is the fastest disturbance which can pass at a stable velocity through the explosive, the surrounding medium will be unaffected until the instant when all the explosive has been converted into hot gas at high pressure.

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‡ The substance of this paper formed part of a thesis accepted by the University of London for the Ph.D. degree.

The walls of the shothole will then be subjected instantaneously to a pressure of the order of several hundred tons per square inch. Apart from some small displacement of the walls of the shothole under this impulsive pressure, the pressure will not fall within the time scale in which we are interested, since the only two available mechanisms, heat loss to the walls and gas escape due to movement of the medium, will require times of the order of milliseconds compared with a time of tens of microseconds required for the generation of a pressure pulse in the medium. The exact form of this pulse is not known, but it will be very nearly of the type of a Heaviside unit function. This may be defined as stage 1 of the mechanism.

In stage 2 the pulse so generated will spread out spherically about the center of the shothole. The stresses initially induced in the medium will greatly exceed the ultimate strength of the medium, and will therefore break it up, forming a complicated crack system, but the medium will not move appreciably in the time of passage of the shock wave, even if a free face is available to facilitate rock movement.

As the spherical pulse moves outwards, the stresses will fall due to the increasing volume of medium occupied by the pulse, and due to the expenditure of energy in forming the new surfaces of the crack system.

At some critical radius the stresses will just equal the elastic limit of the medium and the pulse will have degenerated into an elastic pulse. This marks the end of stage 2.

In stage 3 the elastic pulse will spread outwards spherically and the displacement of the medium will be represented by a formula of the type

$$D_r = \frac{\text{constant}}{r} f(t - r/v) \tag{1}$$

where r is the radius of the sphere, v is the velocity of propagation of elastic waves in the medium, and t is the time. It is now desirable to consider these three stages in some greater detail.

Stage 3 is, of course, the subject of the classical treatment of the propagation of elastic waves (Heiland, 1940; Jeffreys, 1946; and Love, 1934). In a fluid where only compressibility, viscosity and density are necessary to describe the properties of the medium, a fairly complete study of wave motion is possible. A solid medium requires up to 21 elastic constants fully to describe its behavior, although for an isotropic homogeneous medium, these reduce to two. The ground is not a uniform medium and the reflections and refractions at interfaces and their effects in building the complications of the earth movement at a selected measuring point are the special study of seismic exploration geophysicists.

A great deal of useful information has recently been published concerning stage 1. It is possible to calculate by thermochemical methods the static pressure which the explosion products exert on the walls of the shothole (Morris, 1947),

while the hydrodynamic theory of detonation (Paterson 1948) enables the dynamic pressure exerted on the walls by the detonation wave to be calculated from the static values. In addition to such calculated values the Hopkinson pressure bar technique (Davies, 1948), enables experimental measurements of the pulse parameters at the beginning of stage 2 to be made.

Concerning stage 2, however, much greater uncertainty exists. Experimental work carried out under war conditions during recent years (Courant and Friedricks, 1948), (Cole, 1948), has greatly added to knowledge of explosive waves in air and in water, but little is known about the action of explosives on solid media, and in particular on rocks, especially about their behavior under stresses above the elastic limit. Under the extremely fast blows of an explosion, there is little likelihood of plastic flow playing any part in the behavior of rocks.

At first sight it might be thought that a rock could not sustain a stress above its ultimate limit, but this would result in the rock in a thin shell at the surface of the shothole being reduced to exceedingly fine powder and the rest of the rock being undamaged. This is not what really happens. Near the shothole wall the crack system is very fine structured, but becomes coarser until, at the critical radius, it disappears. The explanation of the apparent discrepancy appears to be that most rocks are very strong in compression and comparatively weak in tension. To retain its spherical form the pulse must have radial compression stresses and normal to these tensile forces. The former are transmitted through the rock, while the latter cause failure in the rock and are not transmitted, so that energy to replace the necessary tensile components has continually to be supplied from the energy of the compressive stresses.

If the stress in any medium exceeds the elastic limit, the stress strain curve is concave to the strain axis and the line of increasing strain does not coincide with the line of decreasing strain. In fact there is hysteresis and the area enclosed by the loop is a measure of the non-conservative work done in a cycle on the medium. When a pulse, the stresses in which exceed the elastic limit, is propagated the large stresses will be attenuated more than the small ones, since the area of the hysteresis loop increases more rapidly than the stress, so that, in addition to the loss of amplitude due to work done on the medium, the pulse shape will change as it spreads outwards.

It is known from high speed photographs that in solids and liquids the velocity of the shock wave immediately after leaving a detonating explosive charge is very high, and frequently, in fact, exceeds the detonation velocity in the explosive; modern shock wave theory confirms these experimental observations. Unfortunately it is not possible to take such pictures in media such as rock, nor is there at present an adequate method of calculating the shock wave velocity. There is, however, good reason for believing that the initial shock velocity will, as for liquids and gases, be of the same order as the detonation velocity. This is confirmed by observations made when explosive charges are fired on the surface of rock or concrete when a substantial quantity of energy is transmitted into the

medium. This is only possible if the velocities in the two media are of comparable magnitude, since the density of the explosion products and of the rock are of the same order.

Now in stage 3 the disturbance must be propagated with the velocity of sound, i.e. the velocity with which an elastic disturbance of negligible amplitude will travel, and in passing from stage 2 to stage 3, no discontinuity of velocity is permissible. It will be seen therefore that the velocity of propagation at the beginning of stage 2 is very high, but that this will drop very rapidly at first until it passes smoothly into the sound velocity of the medium at the interface between stage 2 and stage 3, i.e. at the critical radius.

When the displacements are elastic it is well known (Southwell, 1936), that the strain energy per unit volume of the medium, U, is

$$U = \frac{1}{2E}\left[p_1^2 + p_2^2 + p_3^2 - 2\sigma(p_1p_2 + p_2p_3 + p_3p_1)\right] \tag{2}$$

where E is Young's Modulus, σ is Poisson's Ratio, and p_1 etc. are the stresses in three normal co-ordinates. For a spherical wave these are a radial stress p_r and two equal tangential stresses p_t, so that the strain energy per unit volume is

$$U = \frac{1}{2E}\left[p_r^2 + 2(1-\sigma)p_t^2 - 4\sigma p_r p_t\right] \tag{3}$$

with p_r and p_t expressed in terms of the displacement D radially at r

$$\begin{aligned} p_r &= \frac{E}{(1+\sigma)(1-2\sigma)}\left[(1-\sigma)\frac{\delta D}{\delta r} + 2\sigma\frac{D}{r}\right] \quad \text{and} \\ p_t &= \frac{E}{(1+\sigma)(1-2\sigma)}\left[\frac{\delta D}{\delta r} + 2(1-\sigma)\frac{D}{r}\right]. \end{aligned} \tag{4}$$

Since the form of the pulse is not usually known, neither D nor $\delta D/\delta r$ can be evaluated. It is, however, possible to write down the energy equation at the critical radius as

$$W_0 - W_R = 4\pi\int_R^{R+\Delta} Ur^2 dr \tag{5}$$

where U has the form given in equation (3), R is the critical radius, Δ is the length of the pulse in the rock,[1] W_0 is the energy initially supplied to the pulse by the explosive and W_R is the work done by the pulse in forming the crack system up to the critical radius. Since after the critical radius no work is done on the rock,

[1] The length of the pulse is a somewhat uncertain quantity as will be seen from the figures, since the pressure curve cuts the axis at a small angle. For the same reason it is obvious that the integral will not be greatly affected by an uncertainty in the exact time at which the pressure in the pulse becomes negligibly small.

equation (5) is true for any value of r which is greater than R, $W_0 - W_r$ being then a constant quantity.

The initial energy of the shock wave is known to be a function of the velocity of detonation of the explosive, but, since the stresses at the critical radius are dependent only on the properties of the medium, the only effect of increasing W_0 is to increase the value of R. Since the energy in the medium at R is only a very small fraction of W_0, an increase in W_0 will not significantly affect the energy in the elastic wave of stage 3. This is in accordance with the observed fact that the velocity of detonation and power of the explosive used have but little effect on the magnitude of the ground waves from explosives (Taylor, *et al.*, 1946 and Morris, in Press).

Since equation (1) represents elastic transmission, as the wave moves outwards, the form of the function will be constant so that the equation can be written for maximum amplitudes

$$D_r \text{ max.} = \frac{\text{constant}}{r} \quad \text{but} \quad D_R \text{ max.} = \frac{\text{constant}}{R}$$

where R as before is the critical radius, so that

$$D_r \text{ max.} = \frac{R}{r} D_R \text{ max.} \tag{6}$$

Returning to equation (5), W_0 can be found by calculation or by pressure bar experiments,[2] p_r, p_t and E could be evaluated from laboratory measurements of the elastic properties of the rock,[3] but the measurement of R, Δ and W_R presents formidable difficulties.

R could be found by placing strong-motion geophones at various distances from the shothole, recording the amplitude as is sometimes done with an "uphole" geophone, and finding the distance from the center of the explosive charge

[2] Hopkinson pressure bar experiments are usually made with the explosive confined only by the surrounding atmosphere.

The conditions in the borehole when an explosive cartridge is fired in geophysical prospecting are intermediate between the conditions treated above with no release of the explosion products, and the conditions obtaining when an explosive is fired in free air. Usually the hole is tamped by a column of water or mud from a few feet to a hundred feet in length and the pressure in the borehole is released as the column of water is pushed out of the borehole.

Some recent calculations by Paterson (personal communication) made since this paper was written, indicate that, in actual borehole conditions such as are used in geophysical prospecting, the pulse length as it passes into the medium may be up to 30 feet long so that the rapid change in length shown in Figure 1 may be an exaggeration of what happens in stage 2.

Since the behavior of real rocks under very great forces is not known, experimental values of pulse magnitudes have to be used in the approximate numerical evaluation above and, so far as I am aware, Hopkinson pressure bar data are the only facts available.

[3] An uncertainty will be introduced here by the possibility of different behavior of the rock when tested *in situ* or under laboratory conditions.

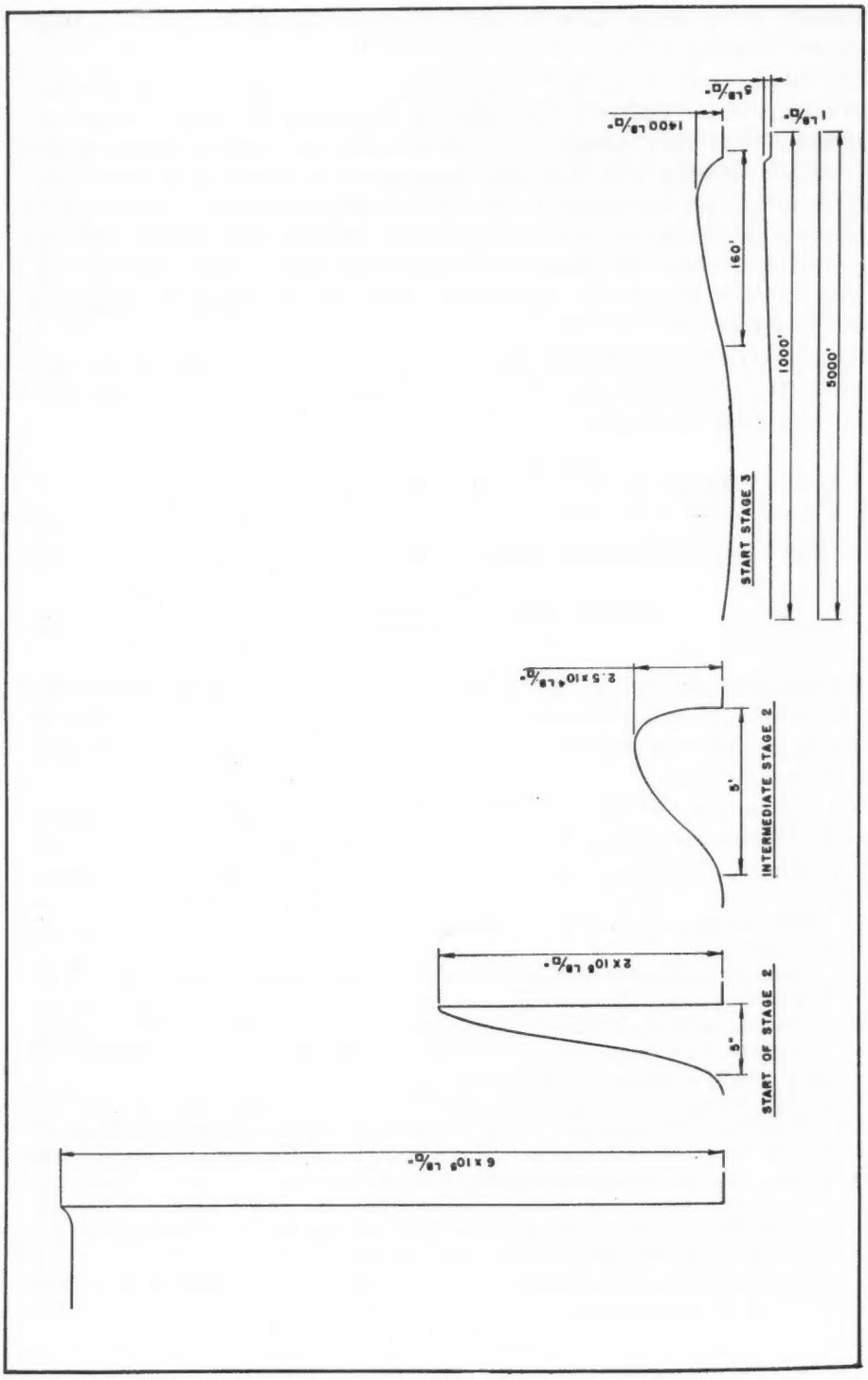

FIG. 1. Pressure time curve.

at which the inverse relation between rock amplitude and distance fails. If then a means could be found of estimating the appropriate value of Δ, W_R could be evaluated from equation (5).

An alternative attack would be the direct measurement of W_R. The work done in forming the crack system is to a close approximation proportional to the new surface area formed, and measurements of the work done in grinding plants would form a possible means of evaluating the relation between work done and new surface. The difficulty would be to measure the area of the surface formed in the crack system. An attempt directly to measure the area of such a crack system would be both difficult and costly.

AN ATTEMPTED QUANTITATIVE EXAMPLE

As has been emphasized above, sufficient information is not available to enable exact calculations to be made, but it is possible to make an informed guess at the magnitudes of the pulse resulting from an explosion at different stages of its career. It is believed that this may be of use to geophysicists as illustrating the mechanism involved.

Consider a typical geophysical explosive having high detonation velocity and a moderately high power, fired in sandstone with the explosive filling the borehole. The initial pressure on the walls of the borehole will be of the order of 600,000 lbs/sq in which will cause a rapid yielding of the walls, and the consequent increase in volume will cause a lowering of pressure which will thereafter decline so slowly as to be practically constant for the small times now being considered. The pressure-time curve of stage 1 will be of the form sketched in Figure 1.

Turning to the beginning of stage 2, it is known (Taylor and Davidson, 1947), that the pulse energy from such an explosive will be of the order of 3,000 ft. lb/sq in and, from pressure bar experiments, that the average width of the main part of the pulse will be of the order of 20μ secs., with an initial peak pulse pressure of the order of 200,000 lb/sq in. But the ultimate compressive strength of, say, sandstone is given by various observers as 8,000 to 20,000 lbs/sq in, an average being 15,000 lbs/sq in. These figures are quoted as applying to samples having the best possible lateral support, but it is very doubtful whether such support can possibly equal that given by rock *in situ*. It may therefore be taken that the rock will be able to carry compressive stresses of up to 25,000 lb/sq in to which figure the pulse maximum will very rapidly fall. This limitation will cause the pulse initially to have the characteristic steep front of a shock wave and a flattened top. The velocity of propagation of the shock wave will initially be of the order of 20,000 ft/sec so that the length of the pulse will be 5 inches.

As the shock wave passes through stage 2, the velocity will fall, reaching the elastic value of about 8,000 ft/sec in sandstone as it passes over into stage 3. At the same time, the peak pressure will fall rapidly, the pulse will tend to broaden. Since experiment has shown that the tensile strength of sandstone is only 1/25 to 1/48 of the compression strength, the maximum rarefaction amplitude will be comparatively small.

As an example of the rapid degradation of the pulse in stage 2, we may cite an experiment by Landon & Quinney (1923), in which it was found that the pressure pulse, generated in a "green" concrete by the explosion of $\frac{1}{2}$ lb of guncotton untamped at its edge, had a maximum pressure after travelling 60 inches of only 1,000 lb/sq in and was 60 inches long, equivalent to a time of about 2.5 milliseconds.

The magnitude of the pulse at the end of stage 2 can best be estimated by equating it to its initial form in stage 3. Up-hole geophone records indicate a half-wave length of about 0.02 second, corresponding to a width in sandstone of about 160 feet.

The change from stage 2 to stage 3 occurs at the critical radius, and is determined by the position at which no further work is done on the medium by the shock wave.

The limiting tensile strength for a sandstone is of the order of 600 lb/sq in as measured in laboratory tests. It is probably higher with the rock in its natural position in the ground.

In a spherical wave having a maximum radial displacement D_r at a distance r from the origin, the maximum hoop tension is given by P_t of equation (4). At the maximum $\delta D/\delta r = 0$ and taking $\sigma = 0.3$, $p_t = 2.6(ED/r)$. Thus at the critical radius we can write

$$\frac{2.6 \times 10^6 D_R}{R} = 600$$

with D and r both in feet, and accepting 10^6 lb/sq in for the value of Young's Modulus. A similar calculation shows that p_r is $6.1(ED/r)$, which will have a value at R of 1,400 lb/sq in.

For a one pound charge of the explosive of this example R will be of the order of four feet, from which D_R is found to be 0.011 inch.

Strong motion vibrograms give a maximum amplitude of the order of $(0.11\sqrt{C})/r$ inch for C pounds weight of explosive at a distance of r feet from the shot point. This motion consists largely of surface wave, but will indicate the order of the pulse amplitude, although the validity of extrapolating to small values of r is extremely questionable.

At $r = 4$ ft for a one pound charge this formula gives an amplitude of 0.027 inch agreeing reasonably well with the previous estimate of 0.011 inch when the excessive extrapolations are considered.

In stage 3 the pressure will fall off rather faster than the distance owing to losses caused by reflection and refraction at the various interfaces, and possibly due to attenuation in passage. Therefore, at 1,000 feet the pressure will be of the order of 5 lb/sq in and at 5,000 feet less than 1 lb/sq in. Since the pulse is now elastic, all its parts will travel at the same speed and its shape will be unaltered as it travels outwards.

In practice, of course, the explosive charges used in seismic prospecting are cylindrical in form and are initiated at one end. The shock wave from such a charge, ignoring the irregular form at the ends of the charge (Jones, 1928), will take the form of a truncated cone, the ends being closed by caps of spheres. This figure will, as the distance from the shothole increases, approach more and more nearly to the sphere which is the simplest form described earlier.

In practice too the shothole is filled with mud, so that before the shock wave enters the rock it has to pass through a layer of liquid. However, it is not thought that this will make the performance of the explosive significantly different from the idealized description given above.

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NOTE ON THE ANALYSIS OF OBLIQUE REFLECTION DATA*

P. HAZEBROEK†

ABSTRACT

A rigorous geometrical solution is given of the problem of determining the location and orientation of a layer from observations at a cross spread, assuming a linear velocity distribution.

INTRODUCTION

From the time differences observed on two seismograph spreads laid out to form a cross the inclination and vertical plane of the ray at the surface can be determined. If distance between shot point and center of spread, the total travel time and the velocity distribution are known, sufficient data are available to determine uniquely the depth of the reflection point and the dip and the strike of the reflecting layer.

The problem has been treated by Horton (1945), who discusses a rigorous solution by a trial-and-error method and two approximate solutions assuming a linear increase of velocity.

On the latter assumption the present paper gives a rigorous geometrical solution of the problem, and the resulting formulae are almost as simple as Horton's (1945), approximate ones.

It is assumed that the reader is familiar with the main properties of the linear velocity distribution.

ANALYTICAL SOLUTION

We define a system of coordinates x, y, ζ as represented in Figure 1. The origin is the point O vertically above the center R of the cross spread in the auxiliary plane at a distance L from the surface. The plane of the emerging ray is taken as $yO\zeta$-plane. The distance $\overline{RS}$ between shot point and center of spread is called d; the coordinates of S are a, b, L, where $a = d \sin \phi$, $b = d \cos \phi$, ϕ being the angle between the direction RS and the plane of the ray, measured as indicated in Figure 2.

The depth of a point below the surface is denoted by z, thus $\zeta = z + L$. The angle i_0 of the tangent in R to the emerging ray with the vertical is known.

The equation of the tangent is

$$\zeta = L + y \cot i_0.$$

The path of the ray is a circle Γ with center in $\zeta = 0$ and belonging to the family of circles

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† Bataafsche Petroleum Maatschappij, The Hague, Holland.

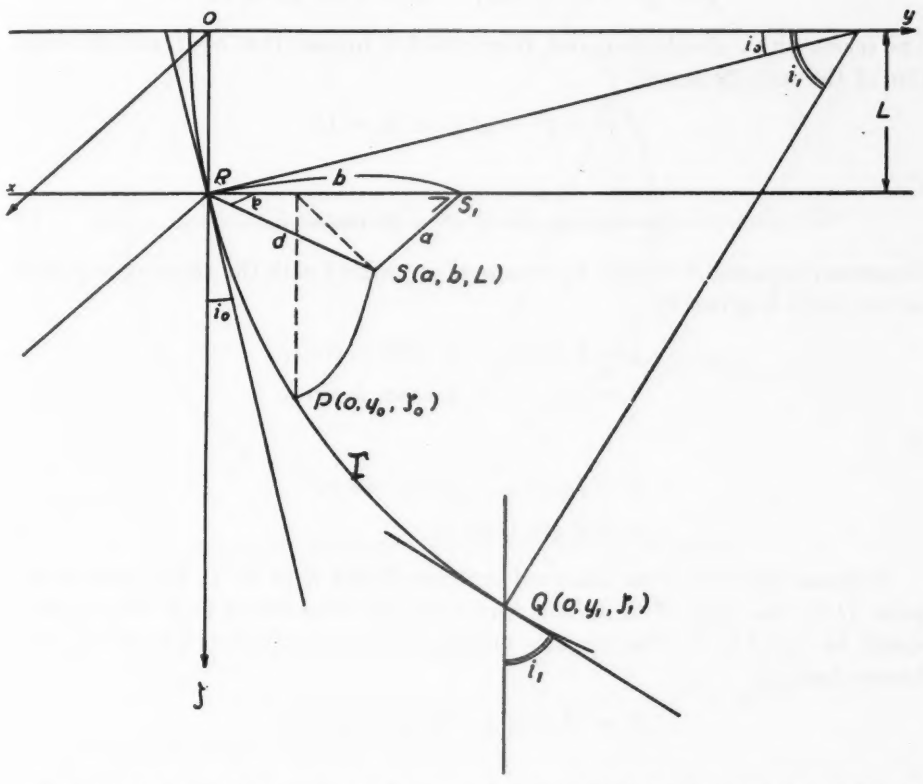

FIG. 1. Definition of the coordinate system used in the analytical solution of the problem to determine location and orientation of a bed from cross spread data, assuming a linear velocity distribution.

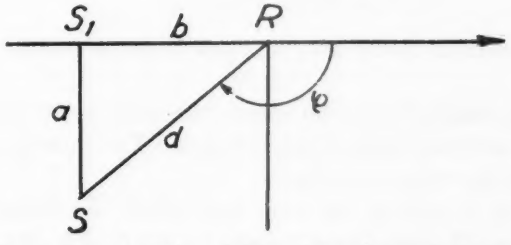

FIG. 2. Representation of shot point and spread system.

$$y^2 + (\zeta - L)^2 + 2\lambda(\zeta - L - y \cot i_0) = 0.$$

The terms with ζ should drop out, from which it follows that $\lambda = L$ and the equation of the path becomes

$$y^2 + \zeta^2 - 2Ly \cot i_0 = L^2$$

or

$$(y - L \cot i_0)^2 + \zeta^2 = L^2 \operatorname{cosec}^2 i_0. \tag{1}$$

Expressed in parametric form by means of the angle i with the vertical, any point on the circle is given by

$$\begin{aligned} y &= L \cot i_0 - L \operatorname{cosec} i_0 \cos i, \\ \zeta &= \qquad\qquad L \operatorname{cosec} i_0 \sin i, \end{aligned}$$

or

$$\begin{aligned} y &= L(\cos i_0 - \cos i)/\sin i_0, \\ \zeta &= L \sin i/\sin i_0. \end{aligned} \tag{2}$$

Suppose the total time observed between S and R to be T. We determine a point Q on the circle Γ in such a way that the total travel time from Q to R would be equal to T. The angle i_1 defining Q can be calculated from the well-known formula

$$T = (L/V_0) \ln (\tan \tfrac{1}{2}i_1/\tan \tfrac{1}{2}i_0)$$

or

$$\tan \tfrac{1}{2}i_1 = \exp (V_0T/L) \tan \tfrac{1}{2}i.$$

The coordinates of Q are

$$\begin{aligned} x_1 &= 0 \\ y_1 &= L(\cos i_0 - \cos i_1)/\sin i_0 \\ \zeta_1 &= L \sin i_1/\sin i_0. \end{aligned}$$

More simply the coordinates of Q and the angle i_1 can be immediately read from a wave front chart.

The crux of our method is to determine the locus of all points which are at equal travel time intervals from Q and from S. The intersection of this locus with the circle Γ is the reflection point P.

Let $M(x, y, \zeta)$ be a point of the locus and denote the coordinates of Q and S by (x_1, y_1, ζ_1), (x_2, y_2, ζ_2) respectively, where (x_1, y_1, ζ_1) are given by equation (3) and (x_2, y_2, ζ_2) by (a, b, L). Then we have for the travel time from M to Q as seen in Figure 3

$$t_{MQ} = (L/V_0) \ln (r_1' + r_1)/(r_1' - r_1)$$

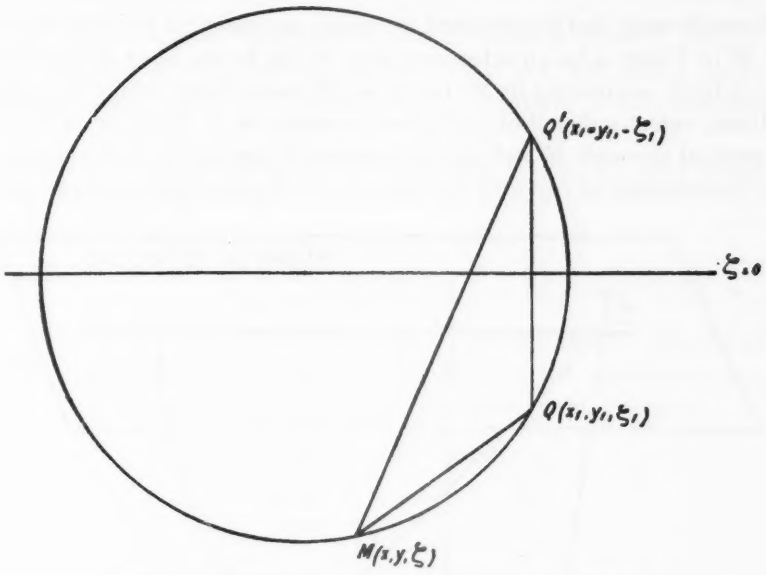

FIG. 3. Representation of travel time between M and Q.

where

$$r_1^2 = (x - x_1)^2 + (y - y_1)^2 + (\zeta - \zeta_1)^2$$
$$r_1'^2 = (x - x_1)^2 + (y - y_1)^2 + (\zeta + \zeta_1)^2 = r_1^2 + 4\zeta\zeta_1,$$

and for the travel time from M to S

$$t_{MS} = (L/V_0) \ln (r_2' + r_2)/(r_2' - r_2)$$

where r_2 and r_2' are defined in the same way as r_1 and r_1' replacing the index 1 by an index 2.

In order to find the locus we put $t_{MQ} = t_{MS}$, from which follows that

$$\frac{r_1' + r_1}{r_1' - r_1} = \frac{r_2' + r_2}{r_2' - r_2}$$

or

$$r_1' r_2 = r_2' r_1$$

or

$$\zeta_1 r_2^2 = \zeta_2 r_1^2.$$

Written explicitly this becomes

$$(\zeta_1 - \zeta_2)(x^2 + y^2 + \zeta^2) + 2(\zeta_2 x_1 - \zeta_1 x_2)x + 2(\zeta_2 y_1 - \zeta_1 y_2)y + \zeta_1(x_2^2 + y_2^2 + \zeta_2^2) - \zeta_2(x_1^2 + y_1^2 + \zeta_1^2) = 0, \quad (4)$$

which is the equation of a sphere Σ with its center in $\zeta = 0$.

This result may also be obtained by purely geometrical methods as follows.*

Let M in Figure 4 be an arbitrary point of the locus. Then S and Q must lie on a wave front originating in M. Let Φ be this wave front, which is a sphere due to the linear velocity distribution. It has its center in A, the point of intersection of the vertical through M and the mid-perpendicular plane of $\overline{SQ}$. Let C be the point of intersection of SQ with the plane $\zeta=0$. In the vertical plane defined by

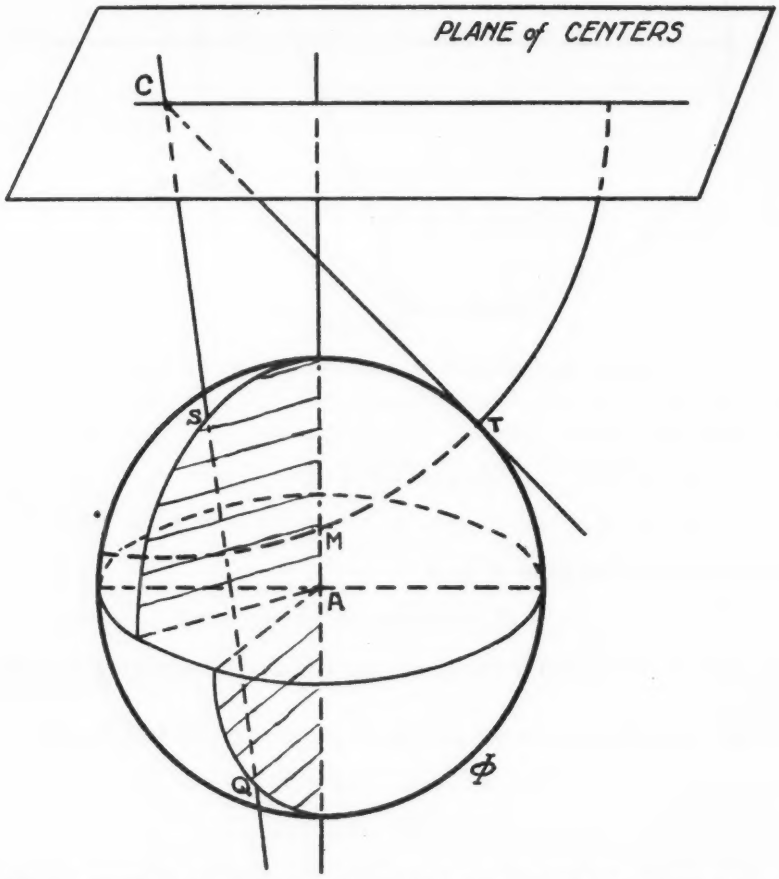

FIG. 4. Geometrical derivation of the equation of a sphere Σ with its center in $\rho=0$.

the points C and M, which has been chosen as the plane of drawing, we draw a circle with its center in C and with a radius equal to $\overline{CM}$. This is a possible ray through M and therefore intersects the wave front Φ perpendicularly. If we call one of the points of intersection T, then $\overline{CT}$ is tangential to Φ. According to a well-known theorem of geometry $\overline{CT}^2=\overline{CS}\times\overline{CO}$; $\overline{CT}=\overline{CM}$, hence $\overline{CM}^2=\overline{CS}$

* This proof is due to Messrs. D. M. W. te Groen and F. Kalisvaart of N. V. De Bataafsche Petroleum Maatschappij.

$\times\overline{CQ}$. This means that all the points M lie at the same distance $(\overline{CS}\times\overline{CQ})^{1/2}$ from C. Hence the locus of M is a sphere with its center in C and with a radius that is the geometric mean of $\overline{CS}$ and $\overline{CQ}$, from which equation (4) may immediately be derived.

Putting $x_1=0$ and substituting the values of (x_2, y_2, ζ_2), and remembering that $\zeta_1-\zeta_2=\zeta_1-L=z_1$, we find

$$z_1(x^2+y^2+\zeta^2)-2a\zeta_1 x-2(b\zeta_1-Ly_1)y - L(y_1^2+\zeta_1^2)+\zeta_1(a^2+b^2+L^2)=0. \quad (5)$$

The sphere Σ and the circle Γ intersect in two points on opposite sides and equal distances from $\zeta=0$, of which the lower one is the reflection point P. Denoting the coordinates of P by (O, y_0, ζ_0) we find without difficulty

$$y_0=\frac{L(y_1^2+z_1^2)-d^2\zeta_1}{2L(y_1+z_1\cot i_0)-2b\zeta_1} \qquad \zeta_0=\sqrt{L^2+2Ly_0\cot i_0-y_0^2}. \quad (6)$$

By substituting for y_1 and ζ_1 their values y_0 can be expressed in terms of the angles i_0 and i_1:

$$y_0=\frac{L^2\{1-\cos(i_1-i_0)\}-\frac{1}{2}d^2\sin i_0\sin i_1}{L\sin(i_1-i_0)-b\sin i_0\sin i_1}$$

or

$$y_0=L\tan\tfrac{1}{2}(i_1-i_0)+\frac{bL\tan\frac{1}{2}(i_1-i_0)-\frac{1}{2}d^2}{L(\cot i_0-\cot i_1)-b}. \quad (7)$$

The sphere Σ possesses the useful property of being tangential to the reflecting surface at the reflection point P. This may be proved in the shortest way by Fermat's principle.* According to this principle the travel time t_{SPR} is a minimum. Therefore, a variation of P to P' in the reflection surface does not increase the reflection time except for second order terms, hence $t_{SPR}=t_{SP'R}$. But now $QP'R$ is a variation of the refraction path QPR, hence $t_{SPR}=t_{SP'R}$, and because $t_{SPR}=t_{QPR}$, $t_{SP'R}=t_{QP'R}$. If $t_{P'R}$ is subtracted from both members of this latter equation, the resulting equality, $t_{SP'}=t_{QP'}$, shows that P' is a point of the sphere. Thus every variation of P in the reflection surface produces a point P of the sphere. This means that the sphere and the reflecting surface are tangential. From this it follows that the radius PC is normal to the reflecting surface which affords a simple means to find formulae for dip and strike of the latter. The coordinates of the center C of Σ are found from equation (5) to be

$$x_C=a\zeta_1/z_1, \qquad y_C=(b\zeta_1-Ly_1)/z_1, \qquad \zeta_C=0$$

or, expressing in terms of i_0 and i_1

* This proof has been given by Mr. H. Rainbow of Shell Oil Company.

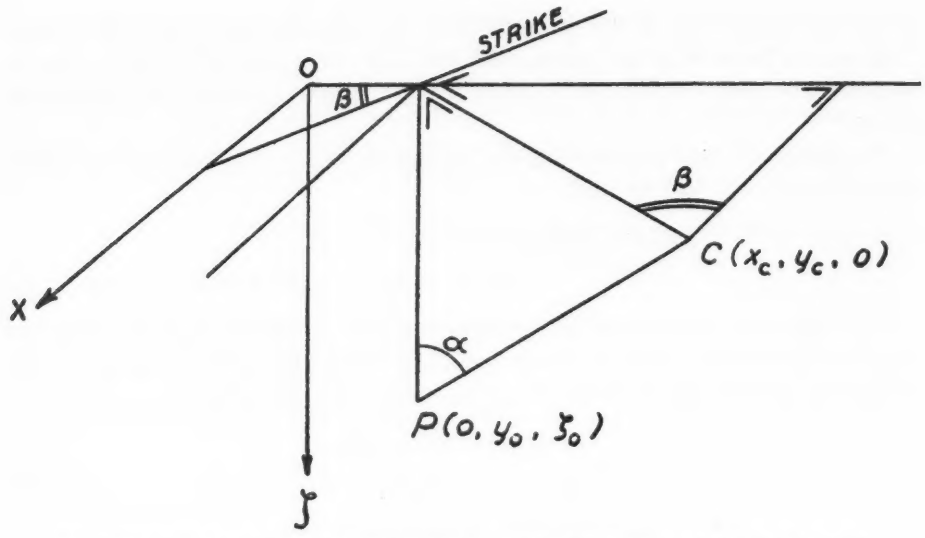

FIG. 5. Representation of the direction of the strike with respect to the plane of the ray.

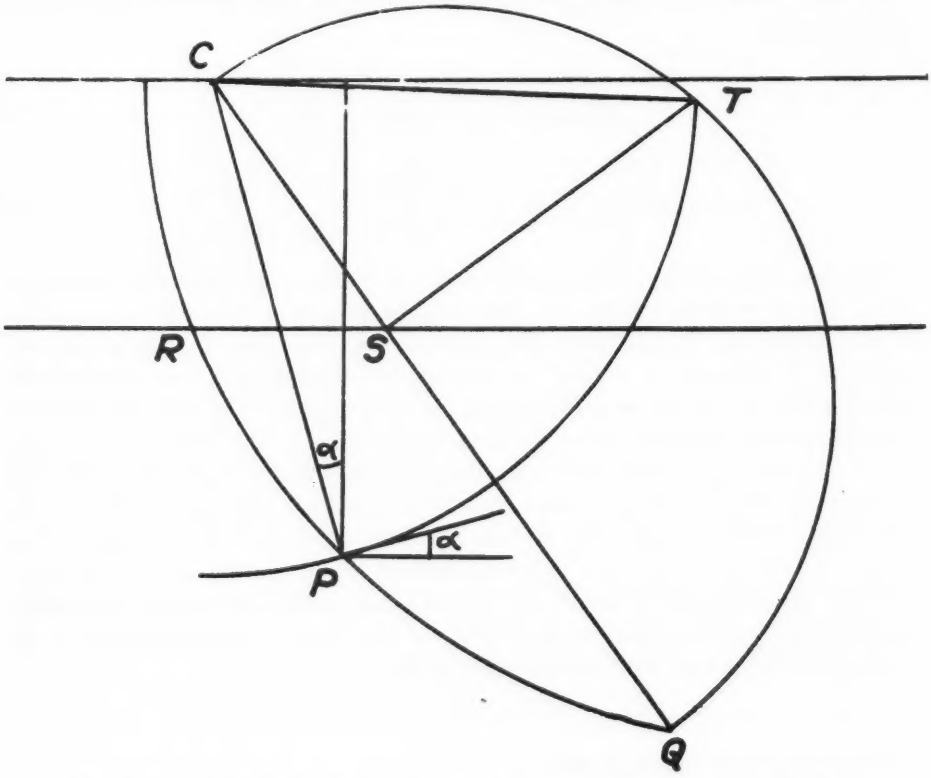

FIG. 6. Geometrical derivation for the case where *RS* is perpendicular to the strike.

$$x_C = a\frac{\sin i_1}{\sin i_1 - \sin i_0}$$
$$y_C = -L\tan\tfrac{1}{2}(i_1 + i_0) + b\frac{\sin i_1}{\sin i_1 - \sin i_0}. \tag{8}$$

Referring to Figure 5 we see that the direction of the strike with respect to the plane of the ray is given by

$$\tan\beta = (y_C - y_0)/x_C. \tag{9}$$

It appears to be most convenient to take β between $-90°$ and $90°$, the sign of β being the same as that of $y_C - y_0$.

The dip is determined by

$$\tan\alpha = (y_C - y_0)/\zeta_0 \sin\beta = x_C/\zeta_0\cos\beta. \tag{10}$$

Equations (6), (7), (8), (9) and (10) enable us to compute rather quickly all the required quantities.

CONSTRUCTIONS

If RS is perpendicular to the strike, the incident and the reflected ray are in one plane and the depth and the dip may be found by the simple construction shown in Figure 6, which is evident without much comment.

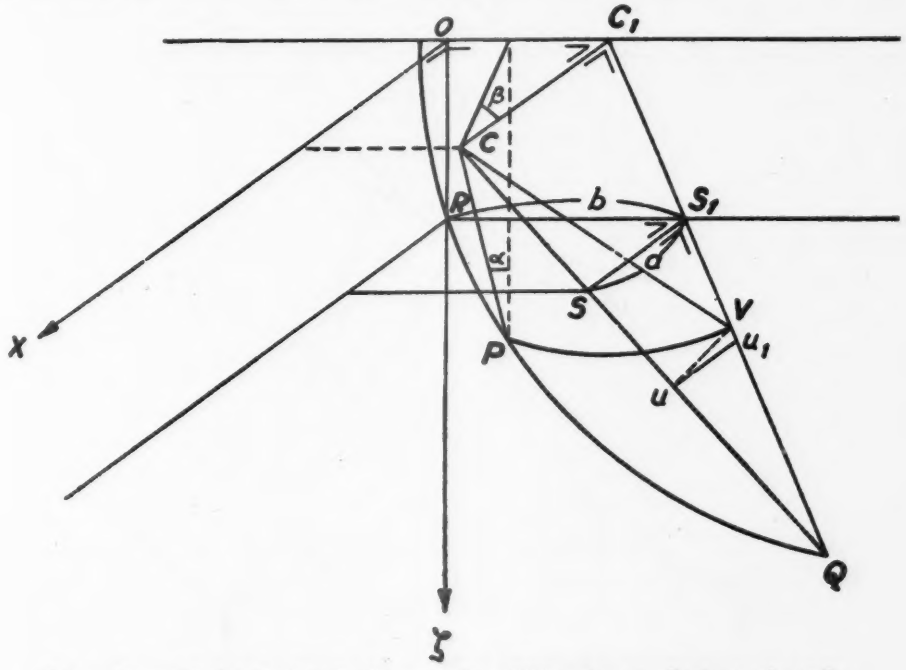

FIG. 7. Geometrical derivation for the case where RS is not perpendicular to the strike.

The ray and Q may be easily constructed or are known from the wave front chart. The radius $\rho = \overline{CT}$ of the locus is the geometric mean of $\overline{CS}$ and $\overline{CQ}$. The dip α follows from the property that the sphere Σ is tangential to the reflecting surface.

If RS is not perpendicular to the strike we have a construction in space which may be performed by the methods of descriptive geometry. There are various possibilities to accomplish this of which the following is recommended because of its analogy to the simpler case described in the first paragraph of this section.

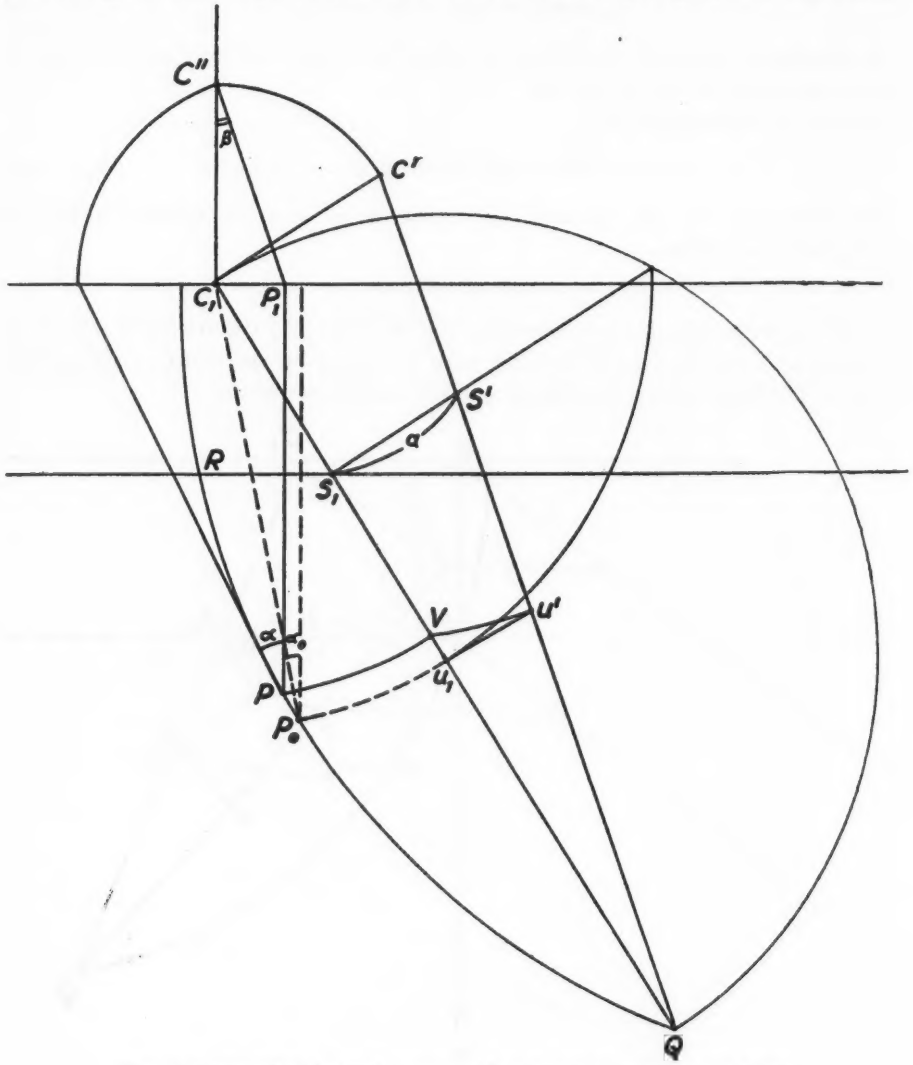

FIG. 8. Geometrical derivation to provide a means to estimate the effect of the offset a on dip and strike.

Consider first the oblique drawing of Figure 7. We consider the projecting plane of CQ on the plane $yO\zeta$ of the ray. Suppose $\overline{CU}$ to be equal to the radius of the sphere Σ, and $\overline{CU}$ is the geometric mean of $\overline{CS}$ and $\overline{CQ}$. Then its projection $\overline{C_1U_1}$ is the geometric mean of the projections $\overline{C_1S_1}$ and $\overline{C_1Q}$. Therefore $\overline{C_1U}$ can be constructed as indicated in Figure 6. The plane CC_1Q is rotated about C_1Q into the plane of the ray and, the offset a being known, CQ can be constructed, thereby determining the center C and the radius $\overline{CU}$ of the sphere Σ; (see Figure 7). The sphere intersects the plane of the ray in a circle with center C_1 whose radius $\overline{C_1V}$ may be found by making $\overline{CV}$ equal to $\overline{CU}$. The reflection point P is found by circling around $\overline{C_1V}$. The position of P being known, the strike and the dip can be easily found.

In Figure 8 the rotated points are indicated by primes.

Owing to our convention concerning the measurement of β the sign of β in Figure 8 has to be taken as negative because C_1 is to the left of P_1. This means that $y_C - y_0$ is negative in equation (8).

The construction provides a means of estimating the influence of the offset a on the dip and the strike, and thus the errors involved in shooting a single spread instead of a cross spread. For a comparison we have constructed the dip for zero offset, represented by dotted lines. One might object to the fact that the projection RS_1 of RS on the plane of the ray is not the actual distance between shot point and center of spread. However, when the angle between RS_1 and RS does not exceed, for example 30°, the method will give a fairly good idea of the influence of the offset.

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A DISCUSSION OF STEEP-DIP SEISMIC COMPUTING METHODS—II*

R. B. RICE†

ABSTRACT

This paper is a continuation of a previous one in which the author gave a comparison of several commonly used steep-dip seismic computing techniques on the basis of the horizontal displacements and depths of the reflection points they produce, assuming a rather "slow" parabolic increase of velocity with depth. In this paper, the comparison of these methods is extended to the case of a second and considerably "faster" velocity function and to the computation of a reflecting horizon through a fault zone. In addition, two other straight-path methods and three purely mathematical methods are introduced and compared in the same manner with the curved-path method.

INTRODUCTION

In a previous paper (Rice, 1949) the author presented a comparison of several commonly used, steep-dip, seismic computing techniques based on horizontal displacements and depths of reflection points that they produce. Formulas for these quantities were derived for the "curved-path," "modified wave-ray," "straight-

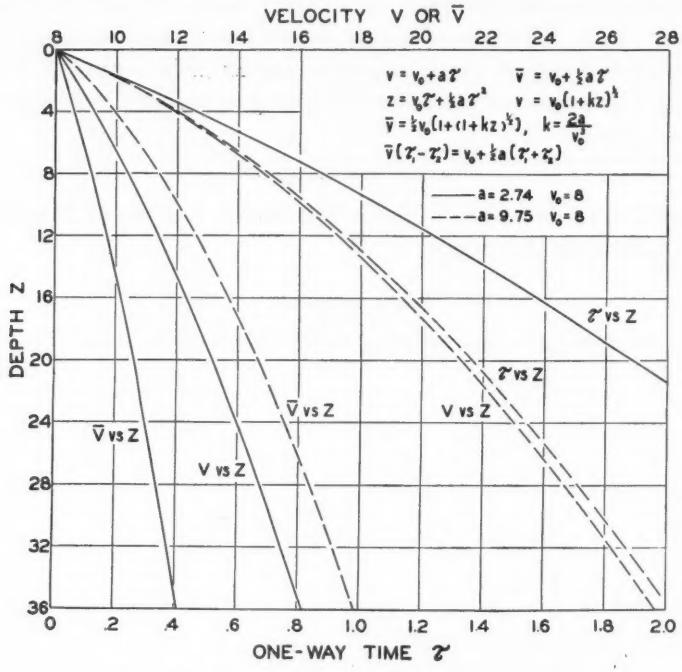
VELOCITY V OR $\bar{V}$
8 10 12 14 16 18 20 22 24 26 28
0 4 8 12 16 20 24 28 32 36
DEPTH Z
$v = v_0 + a\tau$ $\bar{v} = v_0 + \frac{1}{2}a\tau$
$z = v_0\tau + \frac{1}{2}a\tau^2$ $v = v_0(1+kz)^{\frac{1}{2}}$
$\bar{v} = \frac{1}{2}v_0(1+(1+kz)^{\frac{1}{2}})$, $k = \frac{2a}{v_0^2}$
$\bar{v}(\tau_1 - \tau_2) = v_0 + \frac{1}{2}a(\tau_1 + \tau_2)$
a= 2.74 v_0= 8
a= 9.75 v_0= 8
τ vs Z
τ vs Z
$\bar{V}$ vs Z
V vs Z
$\bar{V}$ vs Z
V vs Z
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
ONE-WAY TIME τ

FIG. 1. Velocity curves used in illustrative examples.

* Paper presented at the St. Louis Meeting of the Society, March 14, 1949. Manuscript received by the Editor July 18, 1949.

† Phillips Petroleum Company, Bartlesville, Oklahoma.

path" and "depth-displacement" methods, assuming the velocity to be a parabolic function of depth. In addition, the results obtained for one rather "slow" velocity function over a wide range of reflection and stepout times were compared graphically, and the over-all effect of applying these methods to the computation of a specific steep-dip asymmetric structural profile was illustrated.

In this paper, the comparison of these same methods is extended to the case of a second parabolic velocity function which is considerably "faster" than the previous one used, and to the computation of the profile of a reflecting horizon

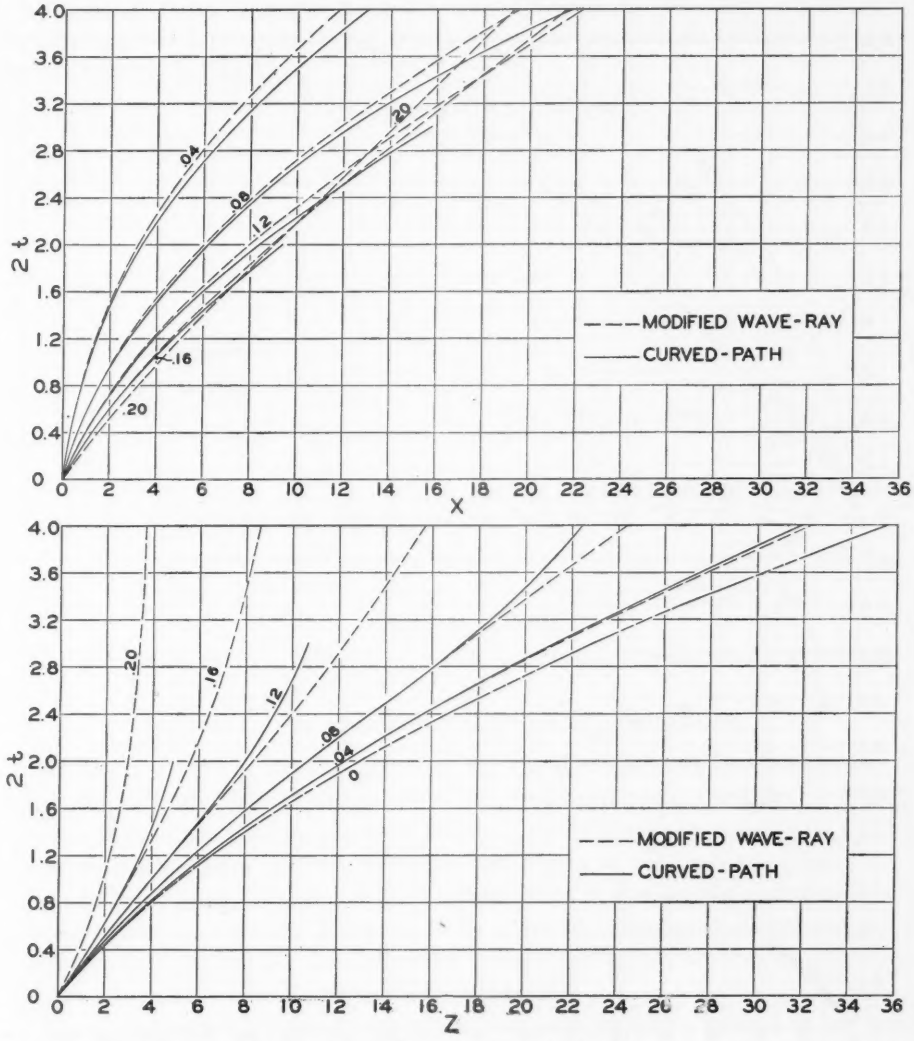

FIG. 2. Comparison of horizontal displacement, X, and depth, Z, of reflection point obtained by modified wave-ray and curved-path methods for velocity function $V=8+9.75\gamma$.

through a fault zone. In addition, two other modified forms of straight-path methods and three purely mathematical methods are introduced and compared in the same manner with the curved-path method.

Figure 1 shows the graphs of the instantaneous velocity, v, versus depth z, the the average velocity, $\bar{v}$, versus depth, and vertical time, τ, versus depth for the two velocity functions considered in this and in the previous paper. Both functions have an initial velocity of 8,000 ft./sec., but the constant a for the slower curve is 2.74 (when the velocity is expressed in thousands of feet per second) while that for the faster curve is 9.75.

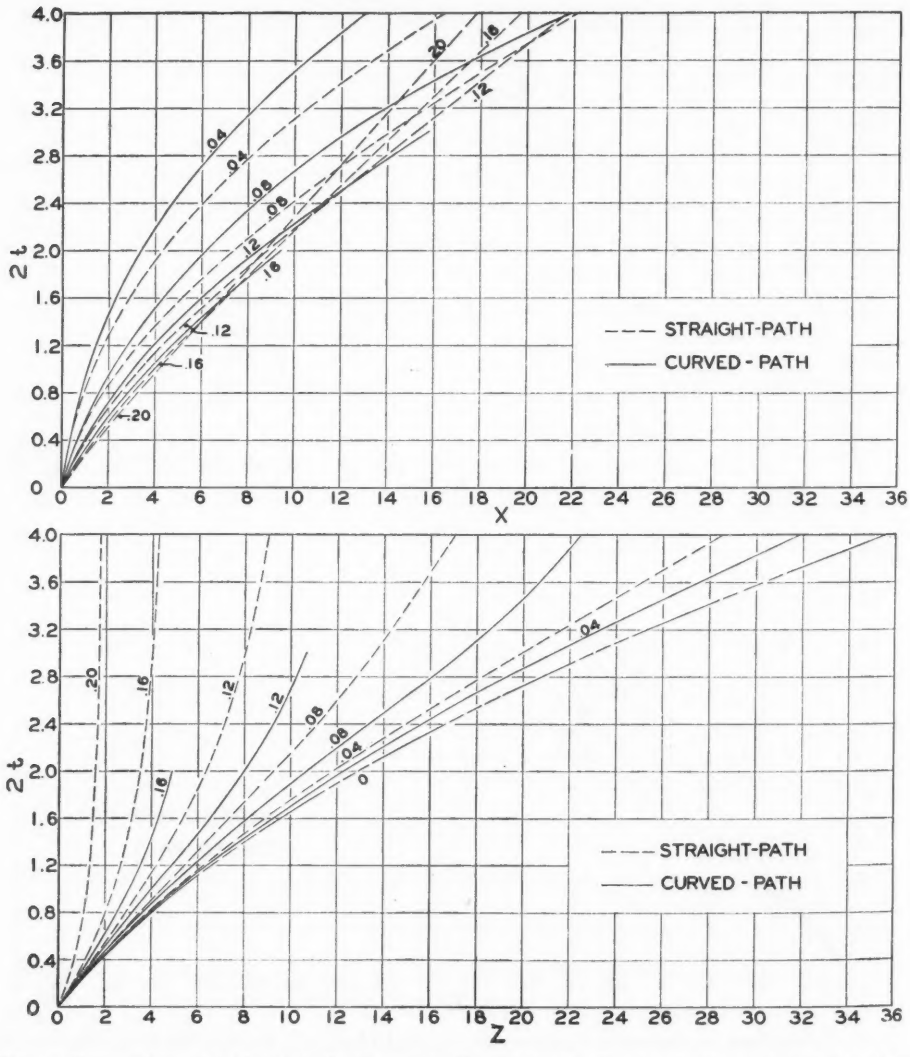

FIG. 3. Comparison of horizontal displacement, X, and depth, Z, of reflection point obtained by straight-path and curved-path methods for velocity function $V=8+9.75\gamma$.

CURVED-PATH AND MODIFIED WAVE-RAY METHODS

The comparison of the results obtained by the curved-path and modified wave-ray methods for the slower velocity function given in the previous paper (Fig. 3) indicated that in this case these two methods give almost identical results for reflection times up to 4 seconds and $\Delta t/s$ ratios up to 0.040. (Δt is the stepout time between two normal paths, and s is the horizontal distance in thousands of feet between the two paths at the datum.) Figure 2 gives the results of the computations using the faster velocity function. It will be noted that there is considerably more divergence of the two methods in this case, although the agreement is still fairly good for reflection and stepout times ordinarily encountered in steep-dip areas.

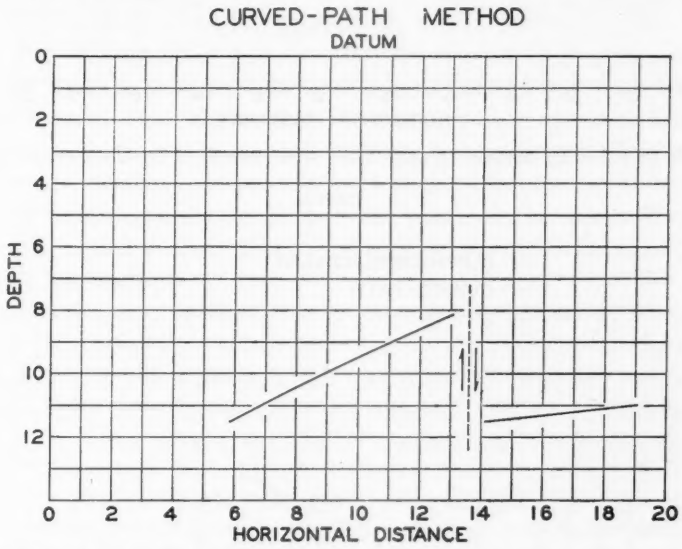

FIG. 4. Profile of reflecting horizon through fault zone computed by the curved-path method.

STRAIGHT-PATH AND DEPTH-DISPLACEMENT METHODS

Figure 3 gives the results obtained by the straight-path method using the faster velocity function as compared to the corresponding curved-path values. A great deal more divergence between the two methods will be noted here than in the case of the slower velocity function (see Fig. 2 of the previous paper).

As an additional illustration of the differences in the results obtained by the various methods, consider Figure 4. Here a set of reflection and stepout times which produce the profile of a reflecting horizon through a vertical fault zone by means of the curved-path method were assumed.

Figure 5 shows the results of applying the straight-path method to the same data. As compared with Figure 4, the fault trace here has been rotated through a positive angle of about 2° to become slightly thrust and has been displaced to the right about 380 ft.

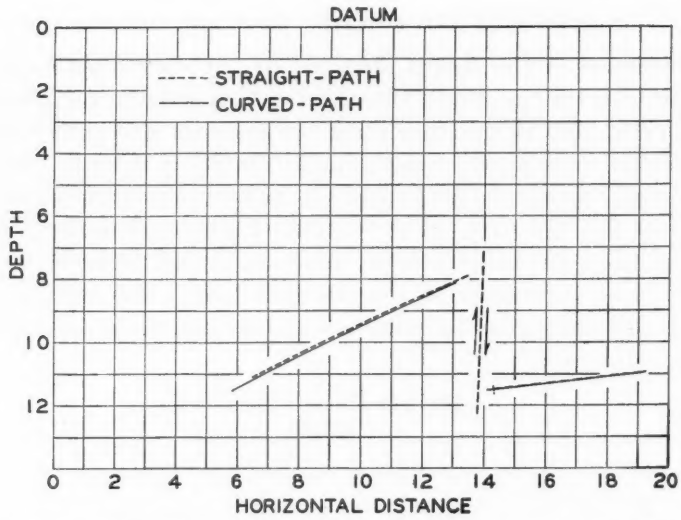

FIG. 5. Profile of reflecting horizon through fault zone computed by the straight-path method.

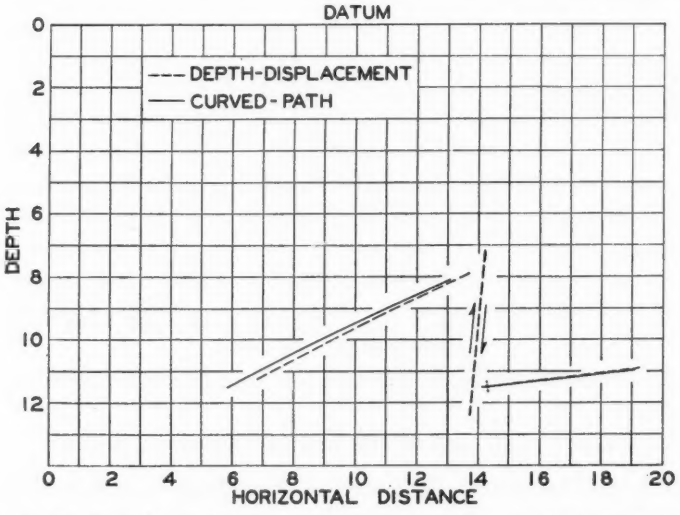

FIG. 6. Profile of reflecting horizon through fault zone computed by the depth-displacement method.

Figure 6 shows the same profile computed by the "depth-displacement" method described in the previous paper. Here, as compared to Figure 4, the fault trace has been rotated through a positive angle of 5° and displaced to the right about 400 ft.

MODIFIED STRAIGHT-PATH METHODS

In all the methods which have been discussed so far (with the exception of the modified wave-ray method), it has been assumed that the isovelocity layers

are horizontal. Two other straight-path methods which assume that the isovelocity layers are parallel to the reflecting horizons (see assumption A_2-2 in the previous paper) will now be presented. Under the assumed conditions, the angle of dip, α, is determined by the formula

$$\sin \alpha = v_s \Delta t/s, \tag{1}$$

where v_s is the interval velocity between the two paths at the datum, Δt is the one-way stepout time between the two paths and s is the distance between the two paths at the datum. As in all straight-path methods, the horizontal displacement, x, and the depth, z, of the point of reflection are given by the formulas

$$x = \bar{v}t \sin \alpha, \tag{2}$$

$$z = \bar{v}t \cos \alpha, \tag{3}$$

where $\bar{v}$ is the average velocity corresponding to the one-way path time, t.

Modified Straight-Path Method #1. If the assumptions discussed above are the only ones assumed, then it is evident that, for a dipping reflecting horizon, the surface interval velocity, v_s, is constantly changing from one point to another on the datum. Hence, one must decide at what point on the datum the initial velocity, v_0, of the velocity curve being used applies. Formulas for v_s and $\bar{v}$ can then be derived as follows.

Let τ_0 be the one-way vertical time to the reflecting horizon at the point where the velocity curve being used is assumed to apply, let τ be the vertical time to the reflecting horizon at any other point and let $\Delta\tau$ be the one-way vertical stepout time corresponding to Δt. Then, since the interval velocity, v_i, between any two vertical times, τ_1, τ_2, for a linear increase of velocity with τ is given by

$$v_i = v_0 + \tfrac{1}{2}a(\tau_1 + \tau_2), \tag{4}$$

the interval velocity at the surface is found to be

$$v_s = v_0 + \tfrac{1}{2}a(2(\tau_0 - \tau) + \Delta\tau). \tag{5}$$

Putting

$$\tau = t/\cos \alpha \tag{6}$$

and

$$\Delta\tau = \Delta t/\cos \alpha,$$

we have

$$v_s = v_0 + a(\tau_0 - t/\cos \alpha + \tfrac{1}{2}\Delta t/\cos \alpha). \tag{7}$$

Similarly, the average velocity, $\bar{v}$, corresponding to τ is given by

$$\bar{v} = v_0 + a(\tau_0 - \tfrac{1}{2}t/\cos \alpha). \tag{8}$$

Since a fourth degree equation is obtained when one tries to solve equations (1) and (7) for α, the practical method of computation for this method is to solve equation (7) for t in terms of Δt and α using equation (1) and compute values of t for various assumed values of Δt and α. Then corresponding values for $\bar{v}$ can be computed from equation (8) and graphs made of x and z versus t for various Δt's from which desired values can be read.

Figure 7 shows the results of applying this method to the computation of the same asymmetric structural profile presented in the previous paper for two different values of τ_0. In the case $\tau_0 = .675$ second, the velocity curve used, namely, the slow velocity curve shown in Figure 1, was assumed to apply at the top of the structure. The surface velocities on either side of this point then become less and less as one goes down the flanks of the structure, and hence the average velocities applied to the flanks are less than those which would be used if the isovelocity layers were assumed to be horizontal. This produces a much flatter and shallower profile than the curved-path method as shown.

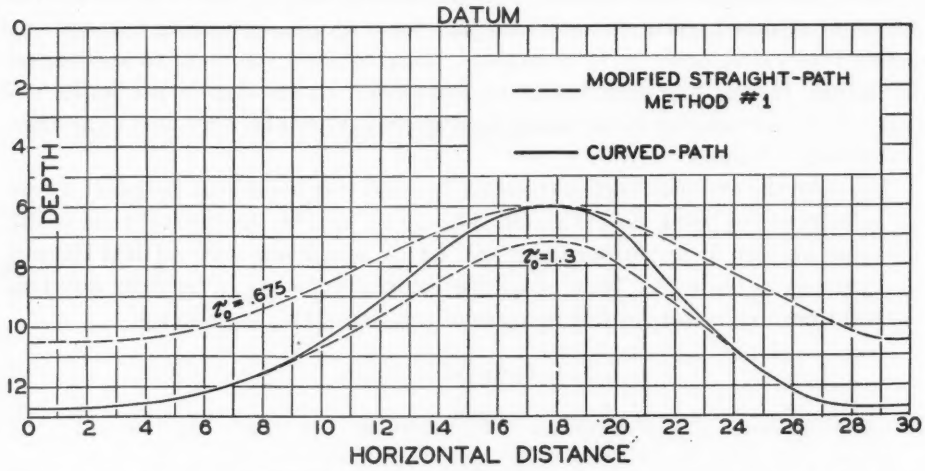

FIG. 7. Comparison of over-all results of applying modified straight-path method #1 and curved-path method to computation of asymmetric structural profile.

In the case $\tau_0 = 1.3$ seconds, the other extreme was assumed, namely that the given velocity curve applies to the deepest part of the structure (horizontal points 0 and 30 in Fig. 7). The surface velocities and average velocities as one goes up the flanks of the structure then become greater and greater, so that the top of the structure is made deeper than by the curved-path method. Of course, any assumed value of τ_0 between these two extremes would give a profile in between the ones shown. But in any case, this method produces a profile with less relief than the other methods.

Modified Straight-Path Method #2. If, in addition to the assumptions made for the method discussed above, one superimposes the common assumption, which

is contradictory to the assumption that the iso-velocity layers are not horizontal, that the same vertical velocity curve applies at all horizontal points, then the surface interval velocity, v_s, between any two points is a constant and equal to v_0, and the average velocity, $\bar{v}$, is given by

$$\bar{v} = v_0 + \tfrac{1}{2}at \cos \alpha. \tag{9}$$

The computation of values for x and z from equations (2) and (3) using equations (9) and (1), with $v_s = v_0$, is then straightforward.

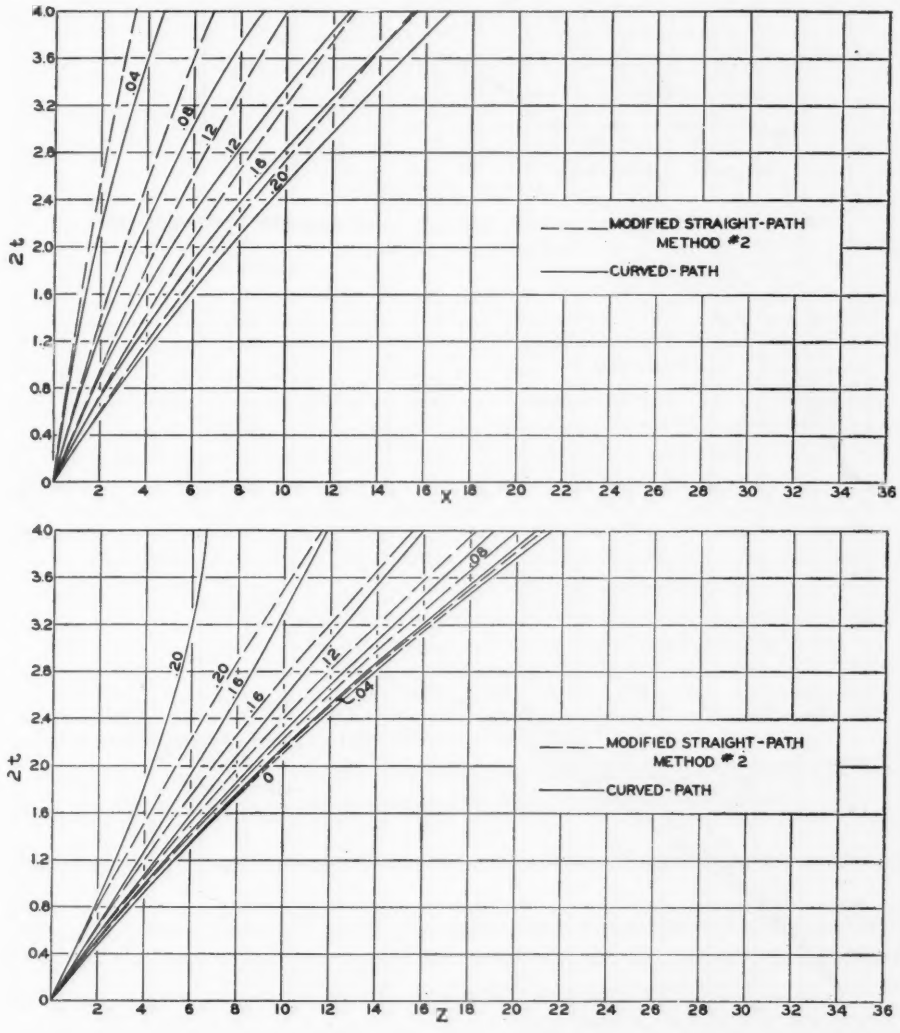

FIG. 8. Comparison of horizontal displacement, X, and depth, Z, of reflection point obtained by modified straight-path method #2 and curved-path method for velocity function $V = 8 + 2.74z$.

Figures 8 and 9 show how the displacements and depths obtained by this method compare with curved-path values for the slow and fast velocity functions of Figure 1, respectively. Note that this method gives considerably smaller displacements and larger depths than the curved-path method, because the low initial velocity, v_0, is used to determine the angle of dip.

Figure 10 shows the results of applying this method to the computation of the same profile through the fault zone considered before. As compared to Figure 4, this method produces a fault trace which has been rotated through a negative

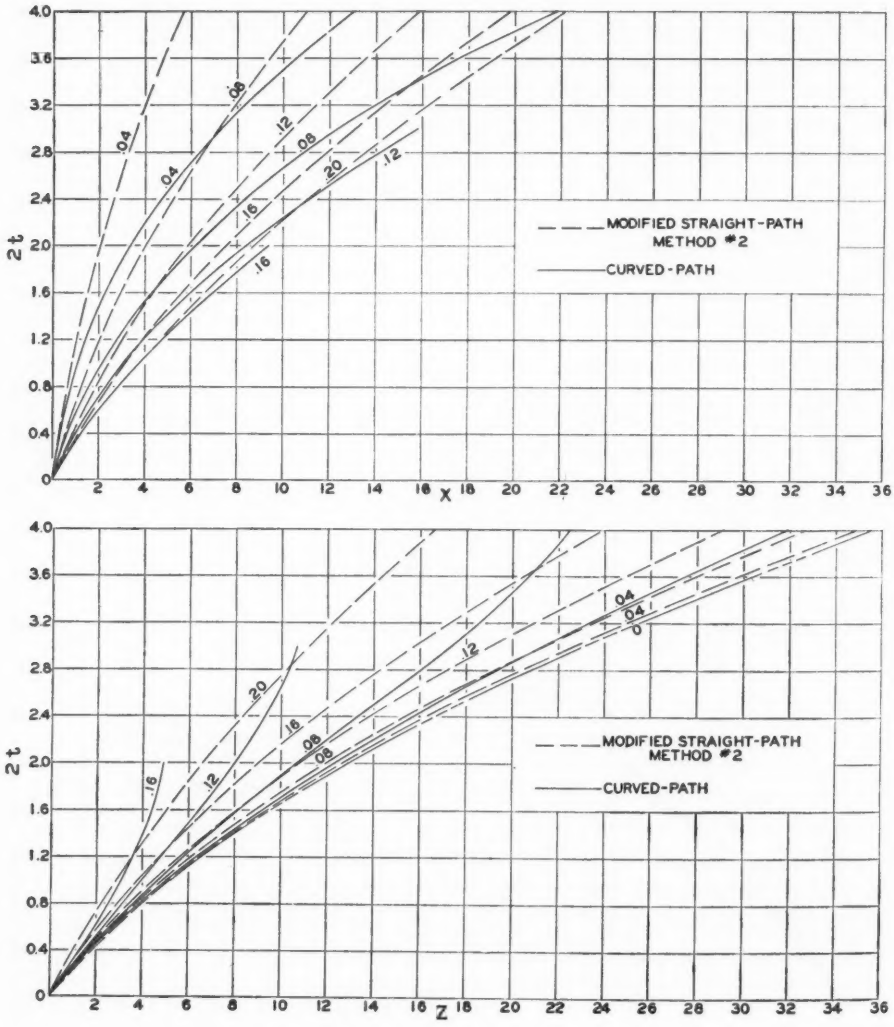

FIG. 9. Comparison of horizontal displacement, X, and depth, Z, of reflection point obtained by modified straight-path method #2 and curved-path method for velocity function $V=8+9.75t$.

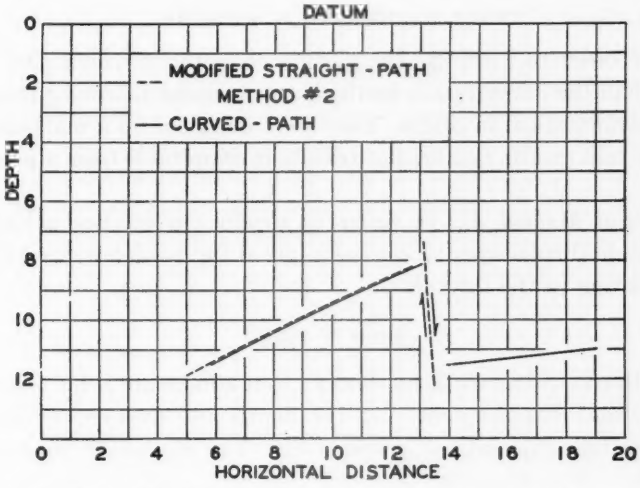

FIG. 10. Profile of reflecting horizon through fault zone computed by modified straight-path method #2.

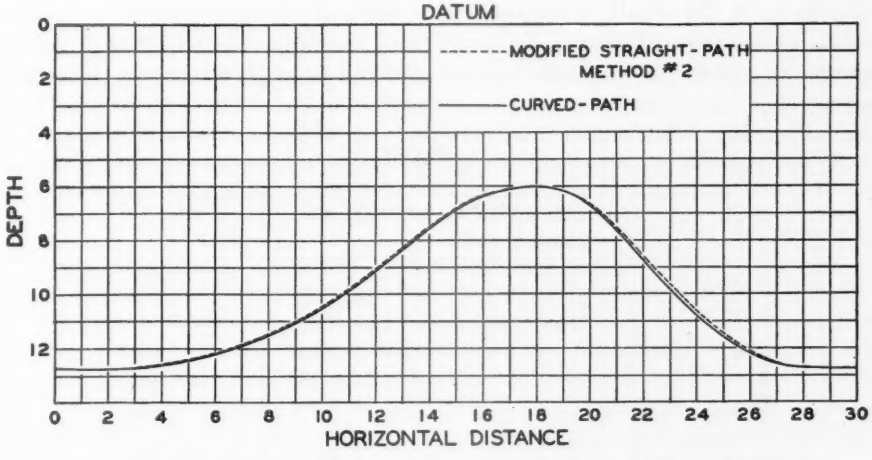

FIG. 11. Comparison of over-all results of applying modified straight-path method #2 and curve-path method to computation of asymmetric structural profile.

angle of about 4° from the vertical and which has been displaced to the left about 270 ft.

Figure 11 shows the over-all effect of applying this method to the computation of the asymmetric structural profile as compared to the curved-path method. Note that in this case, even though displacements computed by this method are considerably less than corresponding curved-path values, the depths are enough larger to cause the points to be moved down the structure, thereby producing only a slightly broader profile than the curved-path one.

THREE MATHEMATICAL METHODS

Finally, in order to complete the picture of methods which give smaller displacements than the curved-path method, consider the following methods which are purely mathematical in origin. They were designed on a mathematical basis to produce certain results and are not readily interpretable from a physical standpoint.

Mathematical Method #1. In order to produce a method which gives the smallest possible displacements, let the angle of dip be determined by the initial velocity according to the formula

$$\sin \alpha = v_0 \Delta t / s \tag{10}$$

as in the modified straight-path method #2, but substitute v_0 for $\bar{v}$ in equation (2) for the horizontal displacement. Let the depth and average velocity again be given by equations (3) and (9), respectively. The method is then described by the formulas

$$x = v_0 t \sin \alpha, \qquad z = \bar{v} t \cos \alpha \tag{11}$$

in conjunction with equations (9) and (10).

Figure 12 is the result of applying this method to the example of the fault trace. As compared to Figure 4, the fault trace has been rotated through a negative angle of about 7.5° from the normal and has been translated to the left by about 430 ft.

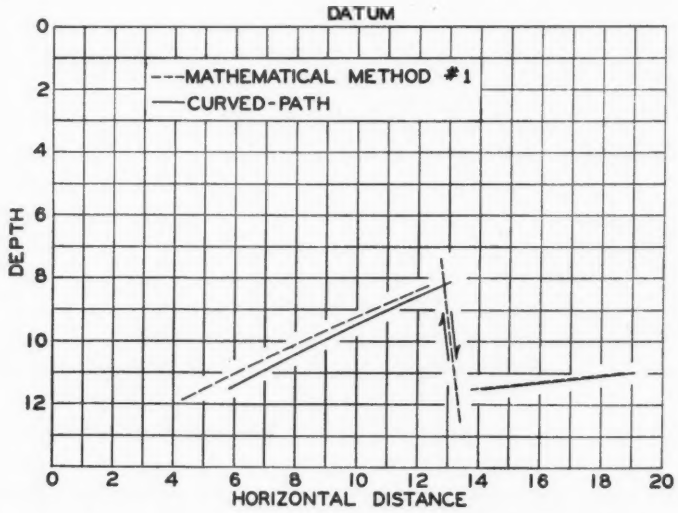

FIG. 12. Profile of reflecting horizon through fault zone computed by mathematical method #1.

Mathematical Method #2. This method is described by the formulas

$$x = \tfrac{1}{2}(v_0 + \bar{v}) t \sin \alpha, \qquad z = \bar{v} t \cos \alpha \tag{12}$$

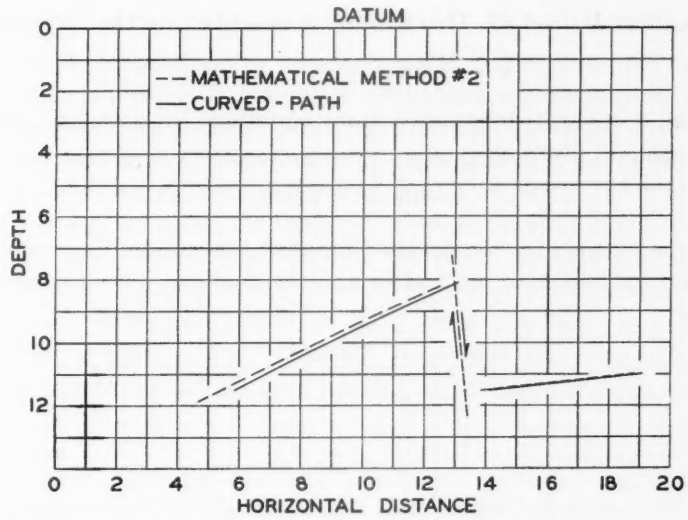

FIG. 13. Profile of reflecting horizon through fault zone computed by mathematical method #2.

in conjunction with equations (9) and (10). Here the depth and angle of dip are given by the same equations as before, but the displacement has been increased slightly by using $\frac{1}{2}(v_0+\bar{v})$ for the coefficient of $t \sin \alpha$ instead of v_0.

Figure 13 shows the fault trace computed by this method. It has been rotated through a negative angle of about 6° and is about 400 ft to the left of the position given by the curved-path method.

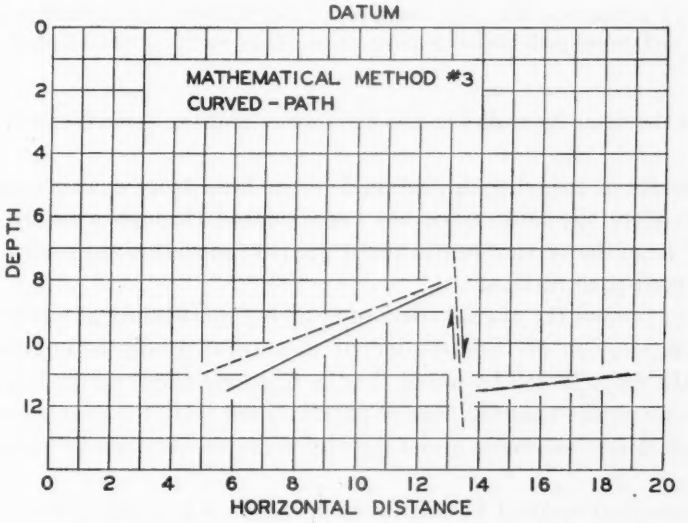

FIG. 14. Profile of reflecting horizon through fault zone computed by mathematical method #3.

Mathematical Method #3. This method is described by the formulas

$$x = \bar{v}t \sin \alpha, \qquad z = \bar{v}t \cos \alpha, \tag{13}$$

where α and $\bar{v}$ are still determined from equations (9) and (10), but where a different angle, α', given by

$$\sin \alpha' = \bar{v}\Delta t/s \tag{14}$$

is used in the formula for the depth. Note that this method is a combination of the modified straight-path method #2 and the modified wave-ray method, since

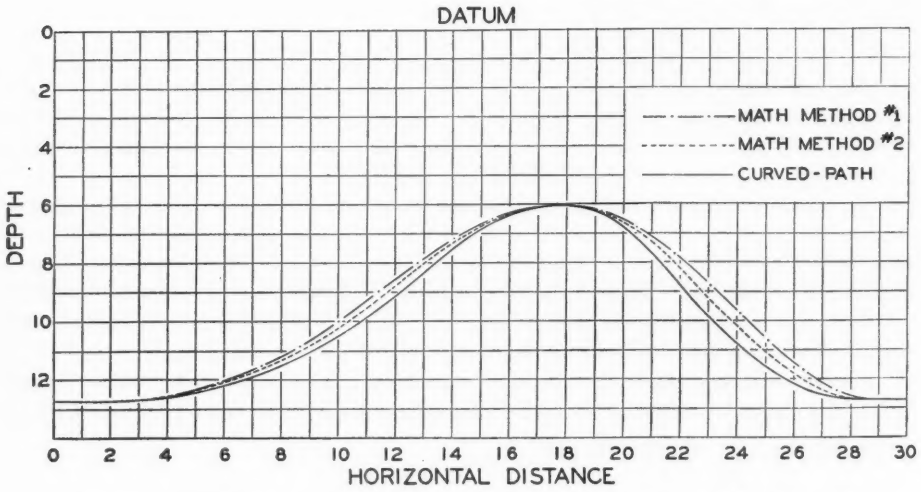

FIG. 15. Comparison of over-all results of applying mathematical methods #1 and #2 and curved-path method to computation of asymmetric structural profile.

it employs the same formula for x as the former and the same formula for z as the latter.

The results of applying this method to the fault-trace example are shown in Figure 14. Here the fault trace has been rotated through a negative angle of about 3.5° from the vertical and is about 270 ft to the left of the position produced by the curved-path method.

Figure 15 shows the overall effect of applying mathematical methods #1 and 2 to the computation of the asymmetric structural profile as compared to the curved-path case. It will be noted that in this case these methods give a somewhat broader profile than the curved-path method, with the profile for the second mathematical method being about equally centered between those for the other two.

Mathematical method #3 was found to produce a profile almost identical to that given by mathematical method #1.

CONCLUSION

The conclusion reached by the author from the studies presented in these two papers is that it is possible to formulate workable steep-dip seismic computing methods to produce any desired results. However, it is believed that there is as yet insufficient data on hand from steep-dip areas to enable one to say definitely that one method is superior to all others from an empirical point of view. Although the methods, which on the basis of our present knowledge have a physical interpretation, would seem to be closer to the truth than those like the purely mathematical ones discussed in this paper, it should be remembered that all our methods are but mathematical models of a complex physical structure about which we know very little as yet. Hence it is possible that the methods that have a physical interpretation are no more correct, or perhaps even less so, than the others.

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RADIOACTIVITY AND MINERALIZATION IN RHYOLITE PORPHYRY*

PAUL E. DAMON†

ABSTRACT

Measurements of the hard gamma radiation from the pre-Cambrian rhyolite porphyry of the Bourbon, Missouri, well core show a direct relationship between mineralization and radioactive content. Low activities are, in general, associated with high mineral density, whereas the mineral density is a function of the magnetite content. The low activities are most probably due to a leaching out of the potassium content. This indicates that gamma-ray well logs should be capable of accurately measuring the location of mineral deposits in potassium rich rock. Potassium analysis of the core is planned by the Missouri Geological Survey.

INTRODUCTION

During the course of an investigation of the radioactivity of the pre-Cambrian section of the Bourbon, Missouri, well core,[1] a direct relationship between mineralization and radioactive content was observed. Although the author is not quite certain to what extent gamma ray well logging techniques have been applied at the present time in the exploitation of ores, he does think a report of this investigation may be of at least some future value to the mining industry.

GEOLOGY OF THE WELL CORE

Three diamond core holes were drilled at the site of the Bourbon magnetic anomaly to ascertain the cause of the anomaly. The pre-Cambrian igneous section of the second drill hole is the one dealt with in this paper. The pre-Cambrian core extended into almost 700 feet of rhyolite porphyry overlain by 1,406 feet of Cambrian and Ordovician sedimentaries.

The following is quoted from U. S. Bureau of Mines Report of Investigation 3961 (McMillan, 1946) which may be referred to for further information. The geologic log for the portion of the core dealt with in this paper is shown (Fig. 1).

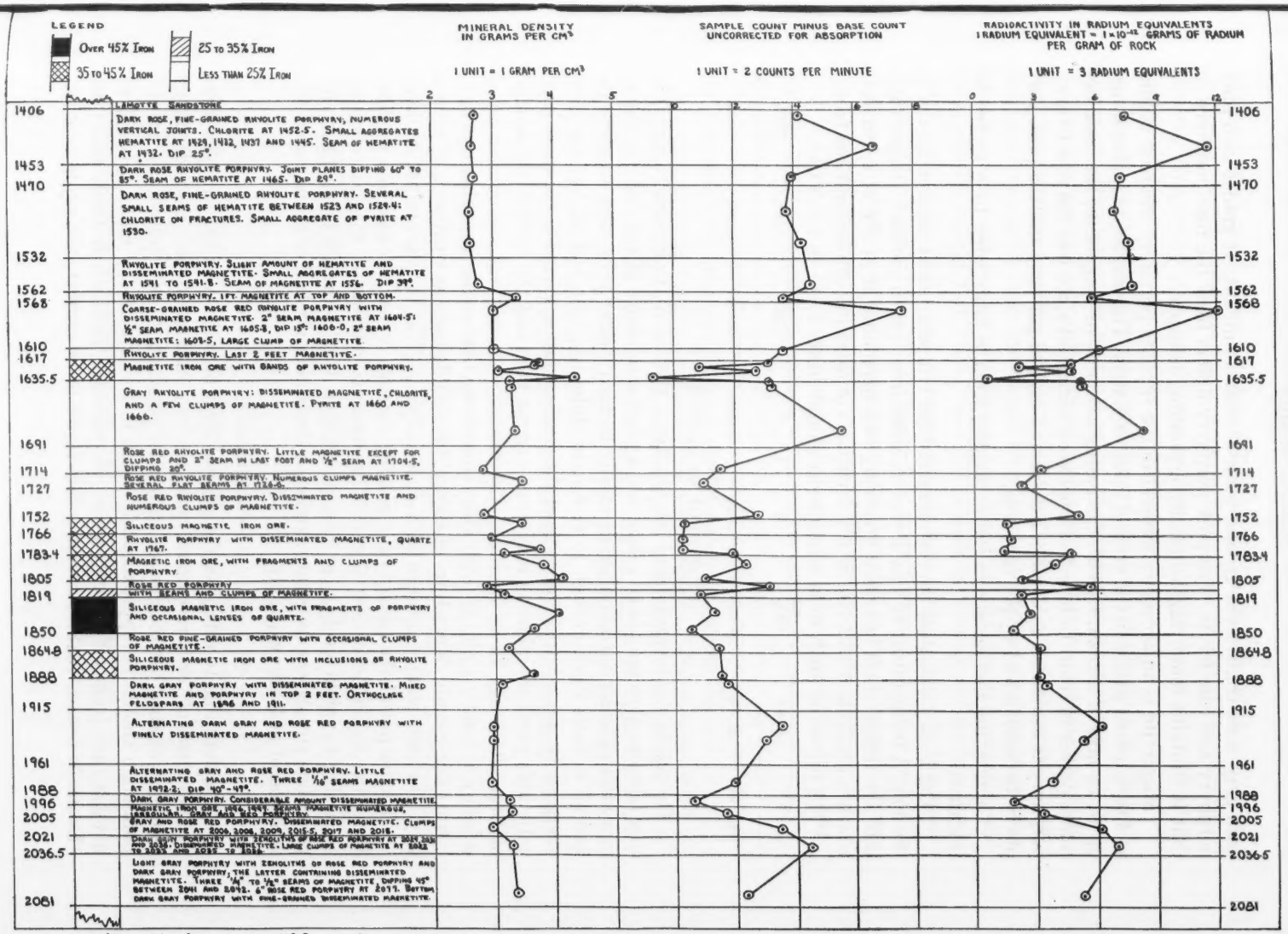
"The Bourbon magnetic anomaly is on the northeastern flank of the Ozark dome, which is the outstanding structural feature of Missouri. The sedimentary rocks of the area, which are mainly dolomites, sandstones, shales and chert, belong to the lower Paleozoic (Cambrian and Ordovician) and rest upon a basement of pre-Cambrian igneous rocks. . . .

"The pre-Cambrian igneous rock encountered in the holes is a rhyolite porphyry similar to rhyolite porphyry of the St. Francois Mountains of Missouri. Rose to gray porphyry composed of quartz and pinkish feldspar phenocrysts in a

* Manuscript received by the Editor April 20, 1949.

† Institute of Science and Technology, University of Arkansas.

[1] This work was carried on while the writer was a graduate student at the Missouri School of Mines and Metallurgy at Rolla. The well core was lent to him by Dr. E. L. Clark of the Missouri Geological Survey with the consent of the U. S. Bureau of Mines.


LEGEND
Over 45% Iron
35 to 45% Iron
25 to 35% Iron
Less than 25% Iron
MINERAL DENSITY IN GRAMS PER CM³
1 UNIT = 1 GRAM PER CM³
SAMPLE COUNT MINUS BASE COUNT UNCORRECTED FOR ABSORPTION
1 UNIT = 2 COUNTS PER MINUTE
RADIOACTIVITY IN RADIUM EQUIVALENTS
1 RADIUM EQUIVALENT = 1×10⁻¹² GRAMS OF RADIUM PER GRAM OF ROCK
1 UNIT = 3 RADIUM EQUIVALENTS
2 3 4 5
0 2 4 6 8
0 3 6 9 12
1406
LAMOTTE SANDSTONE
DARK ROSE, FINE-GRAINED RHYOLITE PORPHYRY, NUMEROUS VERTICAL JOINTS. CHLORITE AT 1452.5'. SMALL AGGREGATES HEMATITE AT 1428, 1432, 1437 AND 1445. SEAM OF HEMATITE AT 1432. DIP 25°.
1453
DARK ROSE RHYOLITE PORPHYRY. JOINT PLANES DIPPING 60° TO 85°. SEAM OF HEMATITE AT 1465. DIP 89°.
1470
DARK ROSE, FINE-GRAINED RHYOLITE PORPHYRY. SEVERAL SMALL SEAMS OF HEMATITE BETWEEN 1523 AND 1529.4'; CHLORITE ON FRACTURES. SMALL AGGREGATE OF PYRITE AT 1530.
1532
RHYOLITE PORPHYRY. SLIGHT AMOUNT OF HEMATITE AND DISSEMINATED MAGNETITE. SMALL AGGREGATES OF HEMATITE AT 1541 TO 1541.8'. SEAM OF MAGNETITE AT 1536. DIP 39°.
1562
RHYOLITE PORPHYRY. LFT. MAGNETITE AT TOP AND BOTTOM.
1568
COARSE-GRAINED ROSE RED RHYOLITE PORPHYRY WITH DISSEMINATED MAGNETITE. 2" SEAM MAGNETITE AT 1604.5'; ½" SEAM MAGNETITE AT 1605.8, DIP 15°. 1606.0, 2" SEAM MAGNETITE; 1608.5, LARGE CLUMP OF MAGNETITE.
1610
RHYOLITE PORPHYRY. LAST 2 FEET MAGNETITE.
1617
MAGNETITE IRON ORE WITH BANDS OF RHYOLITE PORPHYRY.
1635.5
GRAY RHYOLITE PORPHYRY: DISSEMINATED MAGNETITE, CHLORITE, AND A FEW CLUMPS OF MAGNETITE. PYRITE AT 1660 AND 1666.
1691
ROSE RED RHYOLITE PORPHYRY. LITTLE MAGNETITE EXCEPT FOR CLUMPS AND 2" SEAM IN LAST FOOT AND ½" SEAM AT 1704.5', DIPPING 20°.
1714
ROSE RED RHYOLITE PORPHYRY. NUMEROUS CLUMPS MAGNETITE. SEVERAL FLAT BEAMS AT 1716.6'.
1727
ROSE RED RHYOLITE PORPHYRY. DISSEMINATED MAGNETITE AND NUMEROUS CLUMPS OF MAGNETITE.
1752
SILICEOUS MAGNETIC IRON ORE.
1766
RHYOLITE PORPHYRY WITH DISSEMINATED MAGNETITE, QUARTZ AT 1767.
1783.4
MAGNETIC IRON ORE, WITH FRAGMENTS AND CLUMPS OF PORPHYRY.
1805
ROSE RED PORPHYRY
1819
WITH BEAMS AND CLUMPS OF MAGNETITE.
SILICEOUS MAGNETIC IRON ORE, WITH FRAGMENTS OF PORPHYRY AND OCCASIONAL LENSES OF QUARTZ.
1850
ROSE RED FINE-GRAINED PORPHYRY WITH OCCASIONAL CLUMPS OF MAGNETITE.
1864.8
SILICEOUS MAGNETIC IRON ORE WITH INCLUSIONS OF RHYOLITE PORPHYRY.
1888
DARK GRAY PORPHYRY WITH DISSEMINATED MAGNETITE. MIXED MAGNETITE AND PORPHYRY IN TOP 2 FEET. ORTHOCLASE FELDSPARS AT 1896 AND 1911.
1915
ALTERNATING DARK GRAY AND ROSE RED PORPHYRY WITH FINELY DISSEMINATED MAGNETITE.
1961
ALTERNATING GRAY AND ROSE RED PORPHYRY. LITTLE DISSEMINATED MAGNETITE. THREE 1/16" SEAMS MAGNETITE AT 1972.2', DIP 40°-47°.
1988
DARK GRAY PORPHYRY. CONSIDERABLE AMOUNT DISSEMINATED MAGNETITE.
1996
MAGNETIC IRON ORE, WITH ROSE RED PORPHYRY. SEAMS MAGNETITE NUMEROUS, IRREGULAR. GRAY AND RED PORPHYRY.
2005
GRAY AND ROSE RED PORPHYRY. DISSEMINATED MAGNETITE. CLUMPS OF MAGNETITE AT 2006, 2008, 2009, 2015.5, 2017 AND 2018.
2021
DARK GRAY PORPHYRY WITH ZENOLITHS OF ROSE RED PORPHYRY AT 2034, 2035 AND 2036. DISSEMINATED MAGNETITE. LARGE CLUMPS OF MAGNETITE AT 2032 TO 2033 AND 2039 TO 2038.
2036.5
LIGHT GRAY PORPHYRY WITH ZENOLITHS OF ROSE RED PORPHYRY AND DARK GRAY PORPHYRY, THE LATTER CONTAINING DISSEMINATED MAGNETITE. THREE 1/16" TO ½" SEAMS OF MAGNETITE, DIPPING 45° BETWEEN 2041 AND 2042. 6" ROSE RED PORPHYRY AT 2017. BOTTOM DARK GRAY PORPHYRY WITH FINE-GRAINED DISSEMINATED MAGNETITE.
2081

GEOLOGIC LOG REPRINTED FROM U.S. BUREAU OF MINES REPORT OF INVESTIGATIONS 3961

FIG. 1

dark-gray semi-translucent ground mass is most abundant. It grades into pink porphyry and rose felsite. The pink porphyry differs from the rose porphyry in that it contains more megascopically crystalline feldspar.

"Magnetite is an accessory mineral in the rhyolite porphyry where it occurs as disseminated grains in the ground mass or matrix. The magnetite grains range up to 10 mm in diameter. With increasing amounts of magnetite, the rock becomes darker in color. In hole No. 3 between 2,000 and 2,300 feet the rose to gray porphyry is estimated to contain between 15 and 20 per cent and the pink porphyry between 6 and 15 per cent iron.

"Magnetite also occurs as veins ranging from a knife edge to 6 inches in thickness. . . .

"The U. S. Geological Survey measured the temperature at various depths in the hole. A temperature of 59.4°F was recorded from 250 to 500 feet. Deeper than this, the temperature increased gradually to a maximum of 71.0°F at 2,000 feet, which is equivalent to a rise of 1°F for each 130 feet of depth beyond 500 feet."

The following analysis is a composite sample from 1,752 to 1,805 feet:

Fe	Insol.	SiO_2	S	P	CaO	Al_2O_3	TiO_2
43.24	37.61	30.48	0.021	0.023	0.05	3.78	0.92

METHOD OF MEASUREMENT

The method of measurement was similar to that of W. L. Russell (1944). The core samples were ground to a sand and a constant volume of 230 cm^3 was placed in a steel cylinder surrounding an axially located Geiger tube. The Geiger tube had glass walls thick enough to eliminate alpha particles and all but the most energetic beta particles. The walls of the steel container excluded the more energetic beta particles allowing only hard gamma rays and the harder components of Bremsstrahlung to be counted. The sample chamber was surrounded on all sides by at least 7.5 mm of lead. This reduced the base count from about 36 to 16 counts per minute depending, of course, on such factors as weather and time of day. The base count was taken with chemically pure NaCl in the sample chamber.

The output of the Geiger tube was fed through a coaxial cable to a modified Pickering-Neher quenching circuit. The driver circuit was of the gas tube type actuating a typical mechanical message register. Due to the low level of activity, no scaling circuit was necessary, and each determination had to be extended over a period of at least two hours.

CALIBRATION

It is desirable to establish the general level of activity of the samples measured in terms of the hard gamma radiation from radium ($B+C$). Considering the thickness of absorber the gamma rays must penetrate to be counted, one gram of potassium should be approximately equal in its gamma ray effect to the hard gamma rays from 0.85×10^{-10} grams of radium. (Gleditsch & Graf, 1947) and (Evans & Evans, 1948). Assuming this figure to be correct, the equipment was

calibrated with varying percentages of KCl in the sample chamber and it was found that a count difference (sample count minus base count) of one count per minute corresponded to an equivalent radium content of 5.36×10^{-10} grams of radium.

The unit of radioactivity used was the radium equivalent which is the hard gamma radiation produced by 10^{-12} grams of radium per gram of rock.

Since the method of calibration is comparative, that is, comparison of the count produced by a known quantity of radioactive matter with an equal count produced by an unknown, there would be no need for a self absorption correction if the KCl and unknown sample were of the same bulk density (the mass absorbtion coefficients of the RaC, ThC'' and K^{40} gamma rays being so close in value).

Likewise, if the NaCl and unknown sample were of equal density, the same number of base counts would be absorbed in each. However, in every case, the density of the sample was considerably greater than that of the salts used. Therefore, to obtain the true radioactive content of the sample, there must be:

1) A correction of the base count, since more particles originating from outside are absorbed within the sample than within the NaCl used to obtain the base count.

2) There must be a self absorption correction for the absorption in the sample over and above the absorption within the KCl used for calibration.

A semi-empirical absorption correction was derived to distinguish between the apparent radioactivity of the sample and the true radioactive content when self absorption is taken into consideration. However, since the apparent radioactivity and not the true radioactive content is important in well logging, this correction will not be elaborated.

Dr. V. F. Hess of Fordham University kindly provided a sample of Quincy

TABLE 1

DATA FOR QUINCY GRANITE
(Calibration Check)

Sample Number	Mass of Sample	Bulk Density	Base Count Per Hour	Sample Count Per Hour	Count Difference in Counts Per Minute	Count Difference Corrected for Absorption Counts Per Minute	Radium Equivalent Grams $\times 10^{-12}$ R_A Per Gram		Standard Deviation
Q_1	343	1.49	930	1220	4.83	5.46	8.54	±	1.36
Q_2	346	1.50	951	1180	3.82	4.45	6.90	±	1.39
Q_3	355	1.54	957	1233	4.59	5.32	8.06	±	1.37
Q_4	335	1.46	939	1251	5.21	5.84	9.34	±	1.40
Q_5	332	1.44	923	1242	5.32	5.92	9.59	±	1.40
						Average =	8.49	±	.80
							Average Deviation		

granite, which has become one of the most highly analyzed rocks in the world for radioactive content. The total radioactive content in radium equivalents was determined upon the basis of the KCl calibration and compared with the accepted analyses (Hess, 1947). The average of five determinations (Table 1) thus obtained was about 25 per cent too high. It is interesting to note that W. L. Russell (1944), who calibrated his equipment by using known quantities of uranium, thorium and potassium, also obtains higher values for the total radioactive content of samples measured than do other observers who use a different method of measurement. The cause of the rather large discrepancy is not certain but may possibly be due to the differential effect of secondary x-rays (Bremsstrahlung) produced by the higher energy beta particles from the uranium and thorium series on the one hand and K^{40} on the other. The shielding from Bremsstrahlung was somewhat inadequate, since to shield the Geiger tube from these secondaries would reduce the count to such an extent as to make the measurement impractical. Besides, it was desired to make the measurements conform as nearly as possible to the measurement of the radioactivity of the rock in situ.

There is also, of course, the possibility that the gamma ray activity of potassium relative to radium as determined by recent measurements (Gleditsch & Graf, 1947) (Evans & Evans, 1948) has been somewhat overestimated or that the accepted analysis of Quincy granite underestimates its total radioactive content.

Furthermore, there is evidence to support both of these possibilities. Floyd and Borst (1949) recently have obtained a lower value for the specific activity of potassium for gamma ray emission and Hess and Roll (1948) obtain a 15 per cent higher experimental value for the ionization produced by the gamma rays from Quincy granite than for their computed value based upon the accepted analysis. All of these factors may contribute to the discrepancy which, when one considers the low level of activity being measured, is within reason.

At any rate, the radioactive contents listed in Table 2 should be consistent relative to each other but may be somewhat high when compared with analyses by other methods.

ACCURACY OF THE RESULTS

It is desirable to have some estimate of the accuracy of the results in this experiment. Any error in the calibration will not affect the accuracy of the results relative to each other; it will merely shift the magnitude of all values in the same direction.

The relative accuracy is limited primarily by statistical fluctuations in counting rate (Strong), all other errors being small in comparison.

Following Strong, the standard deviation is given by:

$$\sigma = \frac{(N_M + N_B)^{1/2}}{(N_M - N_B)}$$

where N_M = sample count measured with sample in container

N_B = actual base count with sample in container

TABLE 2

DATA FOR CORE SAMPLES

Sample Number	Mineral Density	Count Difference in Counts Per Minute	Radium Equivalent Grams $\times 10^{-12}$ R_A Per Gram		Standard Deviation	Depth
1	2.70	4.18	7.53	±	1.38	1406–1409
2	2.66	6.65	11.63	±	1.40	1435–1437
3	2.70	3.99	7.23	±	1.39	1462–1465
4	2.62	3.74	6.91	±	1.42	1491–1495
5	2.62	4.23	7.66	±	1.39	1519–1521
6	2.78	4.55	7.93	±	1.35	1547–1550
7	3.38	3.66	5.88	±	1.26	1562–1568
8	3.00	7.59	12.08	±	1.28	1574.5–1578
9	3.00	3.61	6.13	±	1.28	1607.5–1615
10	3.78	3.11	4.75	±	1.11	1617–1620.5
11	3.70	.84	2.24	±	>1.48	1620–1623
12	3.06	2.76	4.87	±	1.34	1625–1628.5
13	4.36	−.69	.67	±	> .45	1628.5–1632
14	3.28	3.18	5.24	±	1.21	1632–1637
15	3.31	3.28	5.38	±	1.27	1640–1644
16	3.38	5.56	8.39	±	1.21	1676–1682
17	2.80	1.53	3.25	±	1.60	1707–1711
18	3.46	.96	2.32	±	>1.54	1714–1727
19	2.82	2.78	5.16	±	1.44	1747–1752
20	3.46	.32	1.53	±	>1.02	1752–1759
21	2.97	.27	1.77	±	>1.17	1766–1768
22	3.76	.25	1.46	±	> .97	1773–1778
23	3.13	1.92	4.76	±	1.82	1778.5–1780
24	3.80	2.33	3.94	±	1.28	1783.5–1800
25	4.13	1.02	2.39	±	>1.58	1800–1805
26	2.88	3.15	5.66	±	1.39	1805–1814
27	3.17	.85	2.22	±	1.48	1814–8119
28	4.05	1.30	2.65	±	>1.47	1831–1836
29	3.67	.51	1.81	±	>1.20	1842–1847
30	3.22	1.49	3.09	±	1.56	1856–1864
31	3.66	1.58	3.05	±	1.44	1880–1887
32	3.10	1.77	3.46	±	1.44	1889–1901
33	2.98	3.55	6.11	±	1.27	1925–1932
34	2.98	2.96	5.30	±	1.40	1930–1954
35	2.93	1.93	3.79	±	1.50	1961–1988
36	3.22	.60	1.82	±	>1.21	1988–1996
37	3.26	1.68	3.28	±	1.63	1996–2005
38	2.94	3.46	6.13	±	1.41	2005–2021
39	3.28	4.41	6.92	±	.96	2021–2036.5
40	3.33	2.32	5.30	±	1.74	2042–2081

In all cases where the standard deviation computed by the above formula exceeds two-thirds, the standard deviation is given simply as greater than two-thirds. Most values should fall well within the standard deviation.

A negligible error will be introduced by assuming the radioactive content of NaCl to be zero.

RESULTS

The data are presented in Table 2. The data are also presented graphically together with the geologic log.

The first curve is a plot of the mineral densities of the samples. These densities were determined by the pycnometer method. It is obvious that the mineral densities are directly related to iron content as one would expect, and the mineral density increases steadily with depth.

The second curve is a plot of sample count minus base count uncorrected for absorption. The high counts seem to have no relationship to mineral density, but there is an obvious inverse relationship between low counts and high mineral density. The extremely low apparent activities for the high density ore zone between 1,617 to 1,635.5 feet and the generally lower than median apparent activities for the high density ore samples from 1,752 to 1,888 feet should be noted in this connection. Also the steady decrease of radioactive content with depth parallels the steady increase of mineral density. To make the relationship more explicit the average radioactive content of rock samples falling within different density ranges is given in Table 3.

The third curve is a plot of radioactive content in radium equivalents corrected for absorption. This serves to show that the lower counts for mineralized zones are not an apparent effect due to absorption, but an actual decrease in radioactive content. The absorption corrections would be absurdly large if an attempt were made to explain the low activities on this basis.

TABLE 3

AVERAGE RADIOACTIVE CONTENT FOR DIFFERENT DENSITY GROUPS

Range of Mineral Density gm/cm^3	Number of Samples Falling Within Range	Average Radioactive Content in Radium Equivalents
2.50–3.00	15	6.52
3.00–3.50	16	5.44
3.50–4.00	6	3.08
4.00–4.50	3	1.90

CONCLUSION

V. F. Hess and J. D. Roll (1948) have shown the ionization due to the potassium content of a granite specimen to be more than twice that due to the other components taken together. The potassium content of the rhyolite porphyry in this experiment should be somewhat less than that of the granite specimen, probably nearer 3 per cent than the 3.8 per cent of the granite. However, the potassium content should still supply the majority of counts. Thus the low radioactivity of mineralized sections may be entirely explained on the basis of a leaching out of the potassium content of the rhyolite porphyry. Dr. E. L. Clark of the Missouri Geological Survey supports this hypothesis and a potassium analysis of the 40 samples has been planned.

Mueller (1927) and others have reported an increased radioactivity over mineralized veins. However, the measurements were of the alpha activity of soil

gas due to radon, the gaseous decay product of radium. Radon is readily absorbed by water and therefore is present in some mineralized veins where radioactive water may accumulate in porous and fractured rock. This does not contradict the results of this experiment since alpha particles are so readily absorbed that they are completely excluded from a gamma ray log. It is not necessary to assume that mineralization has any effect on the uranium and thorium content of the rock, a leaching out of the potassium content being sufficient.

If the distribution of radioactivity in this well core proves representative of other potassium rich rock (which seems likely) then a method of accurately measuring the location of ore in wells is indicated.

ACKNOWLEDGMENTS

The writer wishes to thank members of the Missouri Geological Survey and the Physics Department of the Missouri School of Mines, whose interest encouraged him to undertake this project.

Particular gratitude must be expressed to Dr. E. L. Clark and Mr. O. M. Bishop of the Missouri Geological Survey for advice on geologic aspects of the problem; to Dr. Z. V. Harvalik, now of the Institute of Science and Technology of the University of Arkansas, for suggestions on instrument design, and to Dr. H. Q. Fuller, whose wholehearted cooperation as Head of the Missouri School of Mines Physics Department made the project possible.

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BAHAMAS AIRBORNE MAGNETOMETER SURVEY*

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T. C. RICHARDS,‖ AND R. J. WATSON¶

ABSTRACT

This paper presents some of the background prior to the actual survey, the functioning of the "Technical Committee" and its relationship to the contractors. A brief outline is also presented covering the various technical phases of the operation together with some of the inherent hazards of the area and how they were handled. A summary of recommended changes in equipment and procedure arising from the experience of this survey is given.

The largest jointly operated magnetometer survey ever attempted over a predominantly marine area, which came to be known as the Bahamas Airborne Magnetometer Survey, or the BAMS PROJECT to the participants, had its first intimations early in 1946. Two of the companies holding concessions in the Bahamas, Standard Oil Company (N. J.) and Gulf Oil Corporation, acting independently, started early planning with a view toward having airborne magnetic surveys made of their separate concessions. It soon became apparent that two such independent surveys would of necessity be large and costly operations and result in a certain overlapping of the survey arrangements. The next natural step was the realization that a regional survey of this type should be a joint venture, by means of which a larger area could be surveyed and result in a more adequate picture. Consequently, an agreement was drawn up whereby five companies operated as a unit and contracted for a magnetic survey of the Bahamas with Aero Service Corporation of Philadelphia. The airborne magnetometer (Wyckoff, 1948) developed by Gulf Research & Development Company of Pittsburgh, Pennsylvania, was used to make the measurements. The five participating companies and their parent companies are:

1. Anglo-Bahamian Petroleum Company, Ltd. (Anglo-Iranian Oil Co. Ltd.)
2. Bahamas Exploration Company, Ltd. (Gulf Oil Corporation)
3. Bahamas Oil Company, Limited (Superior Oil Company)
4. Shell Company of Bahamas, Limited (Shell Oil Company)
5. Standard Oil Company (Bahamas) Limited (Standard Oil Company, N. J.)

The original contract called for this area to be not less than 50,000 square miles, but it was anticipated that it would cover approximately 85,000 square miles.

The agreement between the five companies provided an arrangement under

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† Sohio Petroleum Co., formerly with Shell Oil Company.
‡ Gulf Research and Development Company.
§ Superior Oil Company.
‖ Anglo-Iranian Oil Company.
¶ Standard Oil Company (N. J.).

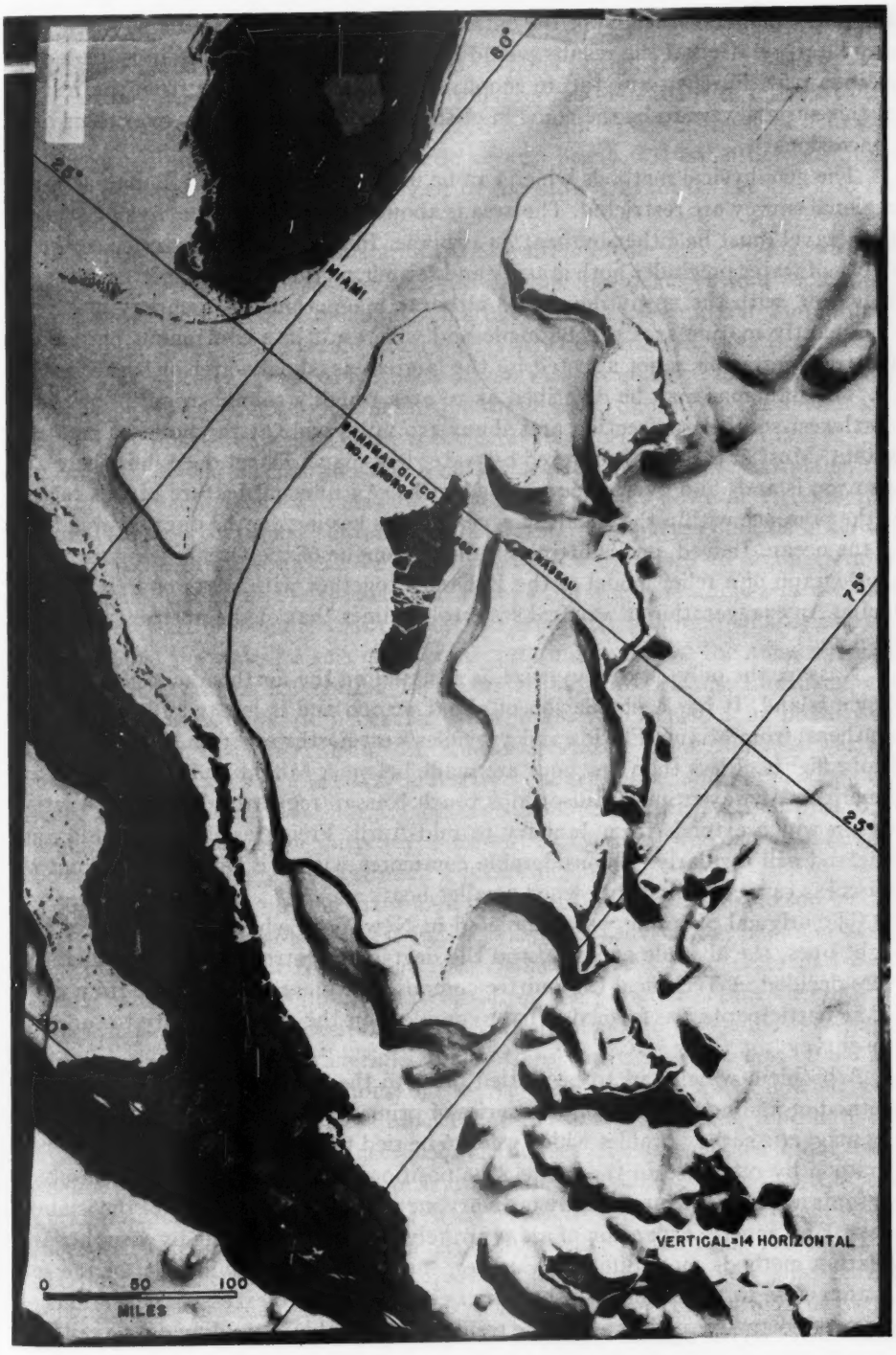


FIG. 1. Relief model of the Bahamas.

which the magnetic results for the entire area would be made available to all, but any interpretation of the results would be done by each company independently as it saw fit. Further, any future geophysical operations arising from the results of this survey were to be the concern of the individual companies over their own concessions.

The geophysical methods which can be used effectively in the Bahamas for a regional survey are restricted. The area is about 90 per cent water covered, therefore travel must be either by boat or airplane. In addition, the extreme range in depth of water precludes both gravity and seismic methods for complete coverage. However, with the newly developed airborne magnetometer, a survey of a predominantly marine area can be made and will result in a continuous map since the transportation is not affected by the land areas, shoal water or ocean deeps.

The Bahamas may be described as an area roughly some 750 miles long in a northwest-southeast direction and about 250 miles wide at the point of greatest extent. Most of the area is covered by water less than 100 feet deep, but there are also 700 islands and over 2,000 exposed rocks. An unusual feature of this region is the presence within the shoals of several areas having depths approaching that of the ocean. Indeed, one is fittingly called "Tongue of the Ocean." Figure 1 is a photograph of a relief model of the Bahamas together with parts of Florida and Cuba. An exaggeration of vertical scale to 14 times that of the horizontal should be noted.

Nassau, the only city of any size, is situated on the north side of New Providence Island. It has a population of about 20,000 and is located 185 miles east southeast from Miami, Florida and 350 miles west northwest from Havana, Cuba. Daily flights of less than one hour are made between Miami and Nassau by Pan American Airways. Some cruise ships touch Nassau regularly during the tourist season which extends from January to mid-April. Freighters from Canada and England call regularly. A considerable commerce with the United States out of Miami is carried by locally owned smaller boats.

The original planning was completed in New York where the spacing of the flight lines, the altitude of flight, and the degree of control over diurnal changes were decided. A Technical Committee composed of one representative from each of the participants was formed to have complete on-the-spot authority to conduct the survey.

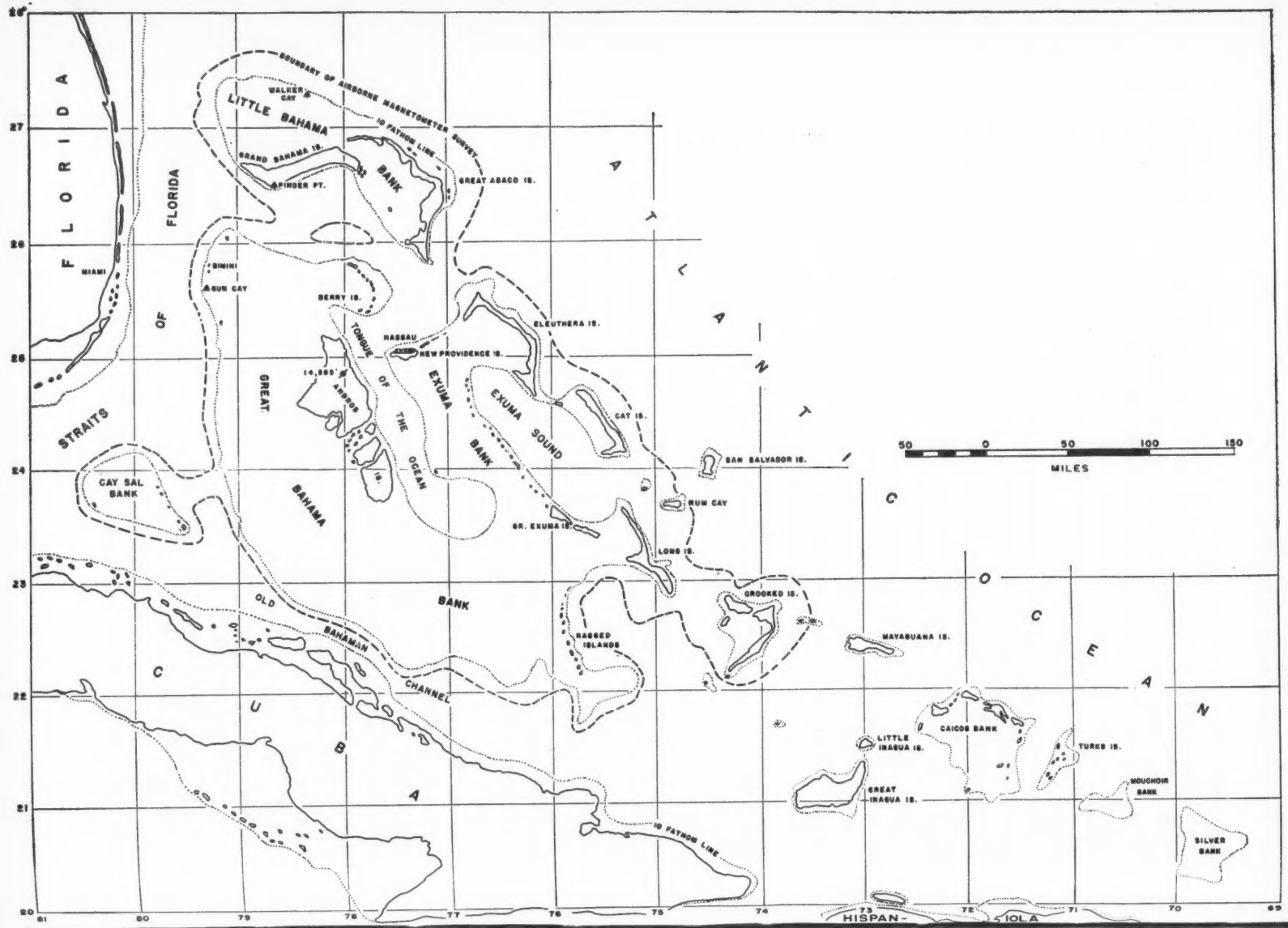
A problem which had to be settled prior to the beginning of flights was the method of finding the position of a series of primary tie points on the ground and the magnetic survey profiles which were to be tied to them. As may be readily understood by reference to the model, the positioning of the tie points themselves presents a formidable problem by ordinary methods. The disposition of the islands makes any general expansion of an accurately measured base line by visual triangulation methods most difficult. Further, the great topographic relief of the sea bottom close to the island and shoal areas is conducive to excessive deflections of the vertical and so renders astrolabe results questionable. Sounding data available

are insufficient to make good corrections for such deflections. Fortunately, there exists in the area three flare-triangulation stations of high accuracy, Walker Cay, Pinder Point, and Gun Cay. These positions were established with respect to the North American Datum (1927) by the Hydrographic Office of the U. S. Navy in 1946. Also, shortly before the magnetic survey began, several other positions, including one at Nassau, had been tied to the same Datum by the U. S. Army using Shoran.

The determination of the instantaneous position of the survey plane with respect to known ground locations was still another problem. Various techniques were discussed. In this predominantly marine area the use of aerial photographs and contact flying is obviously ruled out. There remained at that time Loran, Decca, and Shoran as possible methods. Loran was not believed to have sufficient accuracy. Decca was not available in time to be used. Shoran was available and had already proved its worth in the establishment of primary tie points.

Having decided on Shoran using a master station in the survey airplane, the question of placing the slave stations arose. For a survey flown at 1,500 feet, it seemed unlikely that good contact between master and slave could be obtained much beyond 42 miles unless the slave antennae were raised to a considerable height. Whether suitable positions could be found to work the whole area satisfactorily was a matter of some doubt. Therefore, antennae mounted on boats, about 35 feet above the water, which could move into most parts of the area, were the final choice. Overseas Navigation Incorporated of New Orleans, Louisiana was given a subcontract by Aero Service Incorporated to furnish four boats with crews, maintain them, and to furnish Shoran operators. Some difficulty was encountered in getting suitable boats on relatively short notice, and the participants finally accepted, with some misgivings, four gasoline powered war-surplus craft formerly used for air rescue purposes. Two were 85 feet and two 104 feet in length. Power plants were large Kermath and Packard engines.

Figure 2 shows the outline of the area surveyed and its relationship to Florida, Cuba and other islands of the West Indies. The actual survey was begun in May, 1947, and completed in November, 1947. Some 85,000 square miles had been covered using the same flight line pattern during this period. Lacking adequate or correct maps showing the positions of the various islands, it was decided to begin the survey by establishing Shoran slave stations with respect to two of the accurate flare triangulation positions, one at Walker Cay on the north side of Little Bahama Bank, and the other at Pinder Point on the south side of Grand Bahama Island. A Shoran triangulation network was thus set up and expanded about these two known points. The other flare triangulation station at Gun Cay and the Shoran positions located by the U. S. Army were checked into as the triangulation proceeded. In contrast to the triangulation with theodolites when the angles of the triangles of the network are measured, the Shoran method involves measuring the lengths of the sides of the triangles. This is done by the "minimum path" method, i.e., the minimum value, properly corrected for the height of the air-


FLORIDA
FLORIDA
STRAITS OF
GREAT BAHAMA BANK
LITTLE BAHAMA BANK
BOUNDARY OF AIRBORNE MAGNETOMETER SURVEY
10 FATHOM LINE
WALKER'S CAY
GRAND BAHAMA IS.
SPINDER PT.
GREAT ABACO IS.
MIAMI
BIMINI
GUN CAY
BERRY IS.
TONGUE OF THE OCEAN
NASSAU
NEW PROVIDENCE IS.
ELEUTHERA IS.
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ANDROS
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EXUMA BANK
EXUMA SOUND
CAT IS.
SAN SALVADOR IS.
CAY SAL BANK
RUM CAY
GR. EXUMA IS.
LONG IS.
OLD BAHAMAN CHANNEL
BANK
CROOKED IS.
RAGGED ISLANDS
MAYAGUANA IS.
CUBA
ATLANTIC OCEAN
LITTLE INAGUA IS.
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TURKS IS.
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plane, of the sum of the two distances between the master Shoran station in the airplane and the two ground slave stations at the ends of the side of a triangle is taken.

Surveying with the magnetometer was done by a system of "arc flying" (Burns, 1947), (Dudley, 1947). With two Shoran slave stations placed about 30 miles apart, the airplane flew arcs of circles about one, the "drift" station, with radii increasing by two mile increments until the limit of 42 miles had been reached. The other Shoran slave station was known as the "rate" and at regular integral miles from this station, measured by Shoran, as the airplane flew along a circle of pre-set radius, a fiducial mark was automatically placed on the magnetometer record strip, on a record strip which showed the amount of variation toward or away from the drift station, on another record strip showing the height of the airplane as measured by a radio altimeter, and finally on the film of a Sonne strip camera. This last instrument was used only over land, and the resulting pictures taken together with aerial photographs purchased from the U. S. Navy allowed a greatly improved map of the outlines of the islands to be made.

To follow out the planned pattern of arc flying, it was necessary to have the Shoran slave stations on the boats occupy positions on a grid of about 30 miles. Because of the varying depth of the water which ranged from very deep, where anchoring and holding a position is impossible, to shore lines, and with a very considerable part of the area having depths less than the draft of the boats, the location of slave stations developed into one of the most intricate planning problems of the survey. While the boats did run aground on several occasions, there was a general feeling that the survey was indeed fortunate in not having more time delaying accidents in this area where shoal waters and tidal currents are treacherous.

The provisioning, fueling, and general maintenance of the boats were major problems. A Port Steward and Port Engineer became necessities. The boats were not well suited to the job because of high fuel consumption. Gasoline was burned at the rate of 140–180 gallons per hour per boat, while operating at only reasonable speed, and the high-test fuel was available in the Bahamas only at Nassau. At numerous times during the survey, it was necessary to bring fresh water and fuel to the boats on location to avoid costly delays in the survey. In August, a gasoline shortage developed due to the unavoidable delay in the arrival of the regular tanker. This was during the hurricane season and the boats were at that time working far from Nassau in the southeastern part of the area. Being low on fuel made them especially vulnerable in that they could not go far enough to reach safe harbors. There also developed the possibility that even without a storm the survey might have to stop for want of new boat positions. The emergency measures taken were rather unusual but highly effective. Gasoline was flown from Miami by two different planes. A PBY owned by Bahamas Airways was flown to Miami and filled with fuel. It was then flown to the boat most in need, and some 1,200 gallons were pumped from the plane's tanks to the boat.

At the same time, a DC-4 was chartered from Pan American Airways at Miami and flown with its tanks full and a cargo of 25 drums to Nassau where the only landing field in the Bahamas exists. A total of some 2,500 gallons were thus made available in Nassau on short notice.

During the hurricane season, from July to November, definite plans of action were made to deal with such an emergency. The boat captains were briefied as to usable anchorages and methods of anchoring. Close contact was maintained with the weather authorities. The approach of one very severe hurricane did make it necessary to send the boats on location to Cuba and the plane to Brownsville, Texas, where a needed overhaul was completed. Because of the ever-present possibility that one or more of the boats might have to put into Cuban waters, it became imperative to have the ships' papers and crew lists in order at all times. With the constant changing of personnel from boat to boat to give required rest periods, the paper work was considerable. Crew changes on distant boats were often made by chartered seaplane.

Any project of this type will have problems of its own in addition to those common to all geophysical undertakings. Nassau is a well known tourist resort, and the housing and feeding of never less than 35 men and at times as many as 50 had caused considerable worry prior to the beginning of the survey. Fortunately, the greatest portion of the operation was in the slack tourist months when accommodations could be found. Unmarried men were placed and fed in two staff houses, and the married men found furnished houses. Facilities for the maintenance of the plane and the various surveying instruments, as well as for the staff reducing the field data to contoured maps, were found in buildings formerly used by the R.A.F. at Oakes Field.

A number of radio frequencies were assigned to the survey by the local Telecommunications Board to permit continuous communication between the plane, the Shoran boat stations and the Nassau office which directed the flights. The Nassau Radiomarine station also proved useful in communication with the boats when flights were not being made.

The Technical Committee acted as a coordinator and a clearing house for the project, meeting with the Aero Service representative when necessary. Its duties included defining the exact areas to be flown and laying out an operating program. It likewise had complete and final authority to determine whether or not the results furnished by the contractors satisfied the performance specifications which had been agreed upon, and if any changes were desired, to request such changes directly with the contractor's representative. It also maintained close contact with the contractors as to the operation and maintenance of the marine equipment. It reviewed all accounting and monthly invoices presented by Aero Service. Portions of these were incurred in Pounds Sterling and the remainder in U. S. dollars.

Following the completion of the survey, the participants agreed that out of the experience gained, some remarks and suggestions which might prove useful

in future surveys of this type would be in order. Prior to the actual start of operations, the liaison between the contractor and the Bahamian representatives of the participants was not wholly satisfactory. All agreed that the beginning would have been more efficient had the local representatives been made more aware of how the survey planning was proceeding. Some advantage might have ensued from having the entire operation under the direction of one company instead of the committee representing all five. It was proposed at one time that Gulf alone direct it because of a greater familiarity with the airborne magnetometer. Due to unpredictable problems of this new type of survey, Gulf declined. A smoother functioning committee at the beginning of the operations might have resulted if the Bahamian representatives had had a better understanding of the intent of the early discussions which took place before the signing of the contract. Obviously, this agreement could not cover all unforeseeable circumstances, especially in a new type of survey.

If boats are to be used to carry Shoran slave stations, it is highly recommended that proper boats with Diesel power be used. Not only would there have been a great saving in fuel cost, but the fact that a boat could stay on the job for longer periods of time with only changes in crew would have simplified the planning. In any operation of this type, the overhead charges are of such magnitude that production must be kept to as high a level as possible. During the latter half of the survey, two flights a day were arranged whenever possible. The reduction of the data is a major undertaking. It is highly desirable that the reduction staff be large enough to bring the computations to the point where the quality of the results can be judged as early as possible. This would permit any necessary reflying of an area to be done with the minimum loss in planning efficiency.

The authors believe that Aero Service conducted this large and new type of survey with great skill. The operation of a plane for over 1,000 hours with no serious breakdowns and one period of over 60 consecutive days of instrument flying left little to be desired. The flood of data which results from eight or ten hours per day of magnetometer operation at a speed of 150 miles per hour is staggering. It was not appreciated by either the participants or the operator at the beginning of the survey how large a reduction staff would be necessary to cope with it. In any future survey, the time requirements for the computed data and maps should be given close attention and an adequate staff obtained.

The writers wish to thank the various participating companies for permission to prepare and publish this paper.

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DISCUSSIONS AND COMMUNICATIONS

THE UNITED NATIONS SCIENTIFIC CONFERENCE ON THE CONSERVATION AND UTILIZATION OF RESOURCES

Reported by

M. KING HUBBERT

During the three-week period August 17 to September 6, 1949, there was held at the United Nations headquarters at Lake Success, New York, an international scientific conference dealing with all aspects of the utilization and conservation of natural resources. The conference was authorized by a resolution of the Economic and Social Council in March 1947, who wisely stipulated that it should be limited strictly to an exchange of information, ideas and experience, and should not pass resolutions or otherwise advise or commit member governments. It was to be a scientific rather than a political conference.

Pursuant to this authorization an international organizing committee was formed to plan the conference. The field of natural resources was reviewed and subdivided under the following major headings:

1. Mineral Resources
2. Fuels and Energy
3. Water
4. Forests
5. Land Resources
6. Wild Life, Fish and Marine Resources

In addition, the following topics of more general interest were selected for plenary meetings:

1. The Natural Resource Situation
2. Using and Conserving Resources
3. Resource Techniques of Special Interest to Less-developed Countries
4. Experience in the Interrelated Application of Resource Techniques
5. Summary and Review of the Conference

After such a review member nations were asked to invite participants to the conference and to choose properly qualified people to prepare papers on the suggested topics. In this manner about 500 papers were prepared for the conference, and most of these were available at the time of the meeting in both French and English.

The total number of official participants to the conference was about 600 representing most of the countries of the world except the U.S.S.R. and affiliated countries. About half the participants were from the United States, but Canada, the United Kingdom, France, and India were each represented by strong delegations.

The program of the meeting provided for alternations between section meetings and group or plenary meetings. Plenary meetings were held on all of the first and last two days and each afternoon of every day. Five section meetings were held in parallel on the mornings of all but the first and last two days. It is evident, therefore, that one participant could attend the plenary meetings but only a fifth of the section meetings. Hence a report of this kind can give only an impression of the meeting as a whole, with a few details of particular interest.

Many of the speakers noted that the world population which is now two and a quarter billion people, and doubling once per century, is rapidly getting out of bounds. Food experts showed that to give the present population an adequate diet the world output of foodstuffs would need to be almost doubled, and indicated a need for converting areas now forested to agricultural uses. Forestry experts showed that Europe and North America are already forestry-deficit areas, and that to meet world forestry needs requires most of the existing forests.

Elmer Pehrson of the U. S. Bureau of Mines presented a summary paper showing that of eleven of the industrial metals the entire known and probable world reserves of ores for about half are sufficient for less than a century, at present rates of production. It was then shown that if world per-capita consumption were to increase to that of the United States or even western Europe, the reserves of many of these would be sufficient for but a few years.

A. I. Levorsen summarized undiscovered petroleum reserves by citing a figure of 500 billion barrels, based on estimates of L. G. Weeks, for the land areas of the world, and 1,000 billion barrels for the offshore areas. He concluded, however, that these were only our best present estimates and that they might constitute but a fraction of the estimates 25 years hence, and that the world is assured of ample undiscovered petroleum reserves to meet all demands for several hundred years.

These conclusions were challenged by both Weeks and Hubbert and a lively discussion lasting off and on for two or three days followed. Weeks reviewed his own detailed studies of the probable petroleum content of all the sedimentary basins of the world, arriving at a figure of about 600 billion barrels of ultimate production for the land areas of the world, and a figure of but 400 billion for the continental shelves. As to the uncertainty of these estimates, Weeks thought the true figure would probably lie between −10 and +50 percent of this amount.

Hubbert regarded the figure of 1,500 billion barrels as being of a reasonable order of magnitude but could see no justification for the assumption that future knowledge would prove this to be much too low. Assuming such a figure, and supposing that the ultimate peak of production is only twice the present rate, this peak should be reached by a normal growth curve in about 75 years. Beyond this, production would gradually decline. Hence the supply should not be sufficient for all world demands for more than a century at most.

Although the full effect of the Conference will not be realized until its complete transactions are published (which it is understood is to be soon), in the opinion of this observer its importance is difficult to overestimate. In the first place the relation of human society and its problems to natural resources on a world-wide basis has never been given sufficient consideration in the councils of state; and, in the second place, the existing sciences have traditionally concerned themselves with more restricted problems, leaving to the nonscientist the task of dealing with social affairs which comprise an integration of all the sciences.

The present Conference is, therefore, unique in that for the first time on such a scale scientists have been called upon to review some of the basic problems confronting human society and to do so *as scientists*. At the same time the Conference constitutes a milestone in the advance of science itself in that it explicitly presents the problems of human society as a legitimate domain for scientific enquiry. In the separate fields of the Conference the data presented were mostly already familiar to those working in each field. The ensemble, however, contained much information brought together in one place which otherwise would be almost impossible for one person to assemble. When these are available in the transactions there is little doubt that they will be extensively studied, and may well exercise considerable influence upon future action with respect to such problems.

PATENTS*

4—ACCELEROMETER

U. S. No. 2,481,792. L. D. Statham. Iss. 9/13/49. App. 7/14/47. Assign. Statham Laboratories, Inc.

Electric Angular Accelerometer. An angular accelerometer having a transverse inertia bar pivoted in the housing by a leaf spring and having pins on its sides close to the axis which engage wire filaments whose terminals are brought out through slip rings.

12—ACOUSTIC MEASUREMENTS

U. S. No. 2,475,742. J. H. Hammond, Jr. Iss. 7/12/49. App. 4/17/46.

Apparatus for Producing Reentrant Magnetic Records. An apparatus for making an endless magnetic record on a rotating disc in which the signal from a monitoring pickup is synchronized with the recording signal by comparison on a c-r tube so that the recording speed may be adjusted to give an endless record.

U. S. No. 2,476,445. L. Y. Lacy. Iss. 7/19/49. App. 10/6/45. Assign. Bell Telephone Laboratories, Inc.

Analysis and Display for Complex Waves. A method for obtaining a frequency-time curve of a complex wave by passing the wave through parallel filters whose outputs are rapidly commutated and successively put on a magnetic tape, a loop of the tape being rapidly scanned by a moving pickup and the signal used to control the brightness of a c-r tube spot with synchronous sweep.

U. S. No. 2,478,207. R. S. Robinson. Iss. 8/9/49. App. 9/5/45. Assign. Raytheon Manufacturing Co.

Vibrating Apparatus. A magnetostrictive supersonic vibrator for continuously treating flowing liquid and having a closed magnetostrictive tube mounted at its midpoint inside the liquid flow tube and energizing coils outside the flow tube.

U. S. No. 2,479,551. N. B. Blake. Iss. 8/23/49. App. 9/12/46. Assign. Sun Oil Co.

Harmonic Generator. A harmonic generator in which the amplified output of a tuning fork is applied to a gas-filled rectifier with a resistor and evacuated diode in parallel, the tubes being biased in opposite directions.

U. S. No. 2,480,607. C. A. Rackey and T. H. Phelan. Iss. 8/30/49. App. 1/18/47. Assign. Radio Corp of America.

Audience Reaction Integrator. A device for measuring audience applause and having a microphone whose rectified output charges a condenser whose voltage is measured with a direct-coupled d-c amplifier and meter.

U. S. No. 2,481,247. L. Schott. Iss. 9/6/49. App. 10/10/46. Assign. Bell Telephone Laboratories, Inc.

Visual Representation of Complex Waves. A system for visually depicting a complex wave pattern by passing it through a number of band-pass filters in parallel and with a commutator scanning the rectified outputs which are applied to a c-r tube so as to deflect the beam radially.

16—AIRPLANE FLIGHT INSTRUMENTS

U. S. No. 2,476,032. C. B. H. Feldman and J. W. McRae. Iss. 7/12/49. App. 3/8/44. Assign. Bell Telephone Laboratories, Inc.

Doppler Effect Speed and Drift Indicating System. A system for detecting changes in the slope of terrain in advance of an airplane by radiating a vertical fan-shaped radio beam which is rotated about a vertical axis and observing changes in the beat-note spectrum between the received reflections and part of the radiated signal.

* Abstracts by O. F. Ritzmann, Gulf Oil Corporation.

U. S. No. 2,477,574. F. D. Braddon. Iss. 8/2/49. App. 7/21/47. Assign. The Sperry Corp.

Gyro Vertical. A gyro vertical in which the weight of the rotor acts as a pendulum and having pick-off and torque motors both geared to the suspension axes.

U. S. No. 2,478,956. H. E. Webber. Iss. 8/16/49. App. 7/13/43. Assign. The Sperry Corp.

Tilt Detector and Control for Gyroscopes. A gyro vertical having a gyro carrying on its gimbals tilt detectors made of a gas-filled bulb with a center-tapped V-shaped filament whose change of resistance with tilt actuates precession-inducing torque motors.

U. S. No. 2,478,967. L. Green. Iss. 8/16/49. App. 5/12/44.

Stall Warning Device for Airplanes. An airplane stall-warning device attached to the leading edge of a wing and having an outwardly extending vane which is deflected by the air stream and actuates an electric indicator through contacts.

U. S. No. 2,479,304. H. J. J. Braddick and J. St. L. Philpot. Iss. 8/16/49. App. 9/21/44 and 8/14/45.

Gyroscope. A gyro vertical having a gyro which carries mercury switches connected so that when the gyro drifts off vertical a switch closes the circuit of an electro-magnet which shifts the position of its armature mass so as to cause a precession which corrects the drift.

U. S. No. 2,479,563. T. M. Ferrill, Jr. Iss. 8/23/49. App. 8/2/46. Assign. The Sperry Corp.

Stable Reference Apparatus. An artificial horizon apparatus having a stretched wire kept in sustained vibration in the field of a pendulously-oriented magnet and with the plane of vibration detected by the high-frequency component of emf induced in the wire from a pair of coils fixed to the craft and excited by a high-frequency oscillator.

U. S. No. 2,480,646. W. C. Grabau. Iss. 8/30/49. App. 1/17/45. Assign. Raytheon Manufacturing Co.

Speed Measuring Device. An air-speed meter or flow meter having a source of continuous sound waves which are simultaneously picked up at points having different directions from the source and the phase difference of the picked-up signals observed and indicated as velocity.

U. S. No. 2,480,846. H. Friedman and L. Wolfe. Iss. 9/6/49. App. 1/16/45.

Ice Detector. A wing ice warning device having a source of penetrating radiation held in front of the wing with a Geiger-Muller counter inside the wing connected to a quenching circuit, amplifier and counting-rate meter.

U. S. No. 2,482,424. T. McConnell. Iss. 9/20/49. App. 1/29/46.

Navigation Instrument. A device with articulated linear and circular scales which are set to known wind direction and velocity, desired true course, air speed and magnetic variation and directly indicating the ground speed, drift and required magnetic heading of the plane.

U. S. No. 2,482,504. T. D. Pennington. Iss. 9/20/49. App. 8/12/46.

Inclinometer. An aircraft inclinometer having two pendulums indicating both longitudinal and lateral tilt on a single dial and also having a pair of white signal lights to indicate left and right tilt, a pair of white lights to indicate slight up and down tilt, and a pair of red lights to indicate up and down tilt of over 45°.

U. S. No. 2,482,795. R. W. Philabaum. Iss. 9/27/49. App. 5/27/46.

Ground Speed and Drift Indicator. A ground-speed indicator having overlapping transparent synchronously-rotating discs with radial lines, motion of points of intersection of the lines being synchronized with motion of an image of the ground and speed of the disc-driving motor indicated.

32—BLASTING MACHINE

U. S. No. 2,481,231. R. G. Martin. Iss. 9/6/49. App. 9/19/47.

Safety Device for Setting Off Explosive Charges. A battery-powered blasting machine having a push button switch in one side of the battery circuit and two spring-biased series switches in the other side of the battery circuit, the latter being simultaneously closed by squeezing the blades against a bridging block.

68—COMPUTING DEVICES

U. S. No. 2,476,747. C. A. Lovell. Iss. 7/19/49. App. 4/25/42. Assign. Bell Telephone Laboratories, Inc.

Electrical Computing System. An electromechanical simultaneous equation solver in which the equation circuits are set up by battery-powered variable potentiometers whose output voltages represent the terms of the equations and the voltage representing the sum of all the terms of an equation used to control a servomotor which adjusts all the potentiometers representing terms of the same variable so as to balance its equation circuit.

U. S. No. 2,477,395. D. E. Sunstein. Iss. 7/26/49. App. 4/12/45. Assign. Philco Corp.

Apparatus for Continuously Predicting a Trend in Observed Data. An apparatus which automatically indicates the quality distribution curve of articles from a manufacturing process by testing each article and automatically counting the ones in each quality class and also entering the count into a storage unit whose count is reduced by each test so as to keep the curve up to date.

U. S. No. 2,483,125. R. L. Cummerow and L. K. Davis. Iss. 9/27/49. App. 6/13/46. Assign. U. S. A.

Phase Shifting Potentiometer. A four-phase potentiometer having four linear resistors forming a square with a rotatable contact, the resistors being separated into two vertically-displaced banks each with a separate contactor so as to avoid contact overlap at the corners.

88—CORE TESTING

U. S. No. 2,476,810. E. M. Brunner and E. S. Mardock. Iss. 7/19/49. App. 4/10/45. Assign. Shell Development Co.

Method and Apparatus for Radiological Measurements. A method of determining hydrogen inside a closed container by irradiating the container and also an adjacent absorbing material with fast neutrons for a time, then removing the neutron source and waiting for slow-neutron-induced activity of the absorbing material to subside and subsequently measuring the activity of the absorbing material.

92—DRILL

U. S. No. 2,482,263. J. S. Goodwin. Iss. 9/20/49. App. 11/20/45. Assign. Globe Oil Tools Co.

Roller Bit. A roller bit whose roller teeth are arranged so that they do not all have true rolling action and the sliding effect removes chips from between the teeth.

104—EARTH AUGER

U. S. No. 2,480,372. C. W. Kandle. Iss. 8/30/49. App. 4/27/45.

Reamer for Earth Drilling. An earth auger for enlarging a hole and having a detachable hollow cylindrical pilot which catches the spoil.

U. S. No. 2,480,537. B. F. Arps and F. B. Arps. Iss. 8/30/49. App. 7/26/45.

Posthole Digger Attachment for Tractors. A posthole auger mounted on a tractor frame and driven from a power take-off and having a hydraulic vertical feed.

108—ECHO SOUNDING

U. S. No. 2,475,363. E. E. Turner, Jr. Iss. 7/5/49. App. 4/10/45. Assign. Raytheon Manufacturing Co.

System for Echo Ranging. An acoustic echo ranging system in which a beam of compressional waves is rotated through the sector searched and a directive receiver rotated through the same sector a definite delay time later, with the delay time being gradually varied so as to cover different regions of range.

U. S. No. 2,476,902. G. R. Paine and J. P. McQuire. Iss. 7/19/49. App. 6/10/48. Assign. General Precision Laboratory Inc.

Depth Sounder. A sonic depth sounding apparatus in which pulses are periodically transmitted and if the reflection time exceeds the time between pulses transmission of the next succeeding pulse is cut off.

116—ELECTRIC LOGGING

U. S. No. 2,475,353. H. G. Doll. Iss. 7/5/49. App. 6/13/42 and 10/8/47. Assign. Schlumberger Well Surveying Corp.

Well Surveying Apparatus. Apparatus for generating a fluctuating pressure opposite a formation by a motor which revolves eccentric weights in the well apparatus and measuring the a-c component of the electrofiltration potential.

U. S. No. 2,475,354. H. G. Doll. Iss. 7/5/49. App. 6/13/42 and 10/8/47. Assign. Schlumberger Well Surveying Corp.

Well Logging Equipment. Apparatus for generating a fluctuating pressure opposite a formation by a motor-driven cam which expands and contracts a Sylphon bellows in the well apparatus and measuring the a-c component of the electrofiltration potential.

U. S. No. 2,482,165. W. R. Flatford. Iss. 9/20/49. App. 9/9/44. Assign. Phillips Petroleum Co.

Signal Generator. A device which may be dropped through the drill stem for supplying a-c to the drill and having batteries which drive a vibrator actuating a ratchet which closes a switch by the time the device gets on bottom and connects the a-c output of the vibrator to the drill.

124—ELECTRICAL PROSPECTING

U. S. No. 2,475,827. H. M. Evjen. Iss. 7/12/49. App. 11/6/45. Assign. Nordel Corp.

Electrical Measuring System. A system for detecting balance when low-frequency a-c voltages are compared in opposition, the unbalance being amplified and applied to the control grid of a critically-biased relaxation oscillator.

U. S. No. 2,476,384. J. Razek. Iss. 7/19/49. App. 5/3/44. Assign. Cochrane Corp.

Unbalanced Bridge Compensation. A bridge for measuring impedance ratios by comparison with a pair of variable impedances and having a variable resistance in series with the indicating meter arranged to be varied in opposite sense to one of the variable impedances so as to maintain the sensitivity constant.

U. S. No. 2,481,492. B. S. Bjarnason. Iss. 9/13/49. App. 6/7/45. Assign. Hans T. F. Lundberg.

Intensity, Intensity Ratio, and Phase Difference Measuring System for Geophysical Prospecting. Apparatus for measuring potentials in a-c electrical prospecting in which potentials between three points are compared by comparing one pair with another pair in opposition through a phase shifter and amplifier.

132—ELECTROMAGNETIC PROSPECTING

U. S. No. 2,477,057. C. B. Grady, Jr. Iss. 7/26/49. App. 1/11/46. Assign. Celanese Corp. of America.

Apparatus for Detecting Metal Particles. A system for detecting metal particles on a conveyor belt and in which the belt passes through a verticle loop excited by an oscillator and the field distortion picked up by a symmetrically placed horizontal loop whose signal is amplified.

136—EXPLOSIVE

U. S. No. 2,475,281. E. J. Hanley. Iss. 7/5/49. App. 1/19/45. Assign. Hercules Powder Co.

Delay Electric Initiator. A delay electric blasting cap whose composition is a mixture of selenium, lead, tin with a flame-producing metal, and a flame-spreading material.

U. S. No. 2,475,875. L. A. Burrows and R. M. Girdler. Iss. 7/12/49. App. 8/7/43 and 11/4/47. Assign. E. I. du Pont de Nemours & Co.

Explosive Assembly. A delay device which may be used to connect two lengths of explosive fuse and which has an initial deflagrating charge, a slow-burning composition and a detonating charge.

U. S. No. 2,476,370. E. J. Hanley. Iss. 7/19/49. App. 1/19/45. Assign. Hercules Powder Co.

Electric Initiator Device and Ignition Composition. An electric squib with a short delay time at low temperatures and having an ignition mixture containing selenium and magnesium and a flame-spreading oxygen-yielding material.

U. S. No. 2,477,458. C. R. Johnson. Iss. 7/26/49. App. 12/19/44. Assign. E. I. du Pont de Nemours & Co.

Electric Blasting Cap. An electric blasting cap whose bridge plug is made of two semi-cylindrical pieces of rubber held in the shell under compression by an annular ferrule crimped into place.

U. S. No. 2,477,549. W. F. Van Loenen. Iss. 7/26/49. App. 1/22/47. Assign. The Permanente Metals Corp.

Explosive Composition. A granular explosive made of a magnesium dispersoid with a protective hydrocarbon coating and a solid oxidizing agent.

U. S. No. 2,478,415. R. J. Miller. Iss. 8/9/49. App. 5/22/48. Assign. E. I. du Pont de Nemours & Co.

Blasting Initiator. A delay electric blasting cap having two compartments with a metal wall separating the delay charge from the ignition charge.

U. S. No. 2,478,838. G. F. Rolland. Iss. 8/9/49. App. 3/3/45. Assign. Atlas Powder Co.

Electric Explosion Initiator. An electric blasting cap which is insensitive to static electricity and whose leg wires have metal tabs which are insulated from the shell by a thin insulating tube having a conducting surface.

U. S. No. 2,481,696. F. R. Seavey. Iss. 9/13/49. App. 9/11/46. Assign. Olin Industries, Inc.

Electric Firing Device. An electric blasting cap whose leg wires extend beyond the bridge connection and are bent so as to mechanically protect the bridge wire and bead.

U. S. No. 2,481,795. J. Taylor and O. A. Gurton. Iss. 9/13/49. App. 1/17/45 and 11/15/45. Assign. Imperial Chemical Industries Ltd.

Explosives Suitable for Safety Blasting Explosions. A low-power detonating explosive of ammonium nitrate and an explosive sensitizer together with an oxidizable ammonium salt and an insoluble metal carbonate which provide two ammonium radicals and one carbonate radical for every three molecules of ammonium nitrate.

U. S. No. 2,481,814. G. A. Brecker. Iss. 9/13/49. App. 1/2/41. Assign. The Philadelphia and Reading Coal and Iron Co.

Connecting Sleeve for Dynamite Cartridges. A collapsible paper sleeve for joining dynamite cartridges end to end.

U. S. No. 2,482,089-091. L. F. Audrieth and D. D. Sager. Iss. 9/20/49. App. 3/20/44. Assign. U. S. A.

Method of Making a High-Density Explosive. A method of preparing a high-density explosive containing TNT by dissolving and suspending the other constituents in a liquid melt of the TNT and allowing it to solidify.

140—FLAW DETECTOR

U. S. No. 2,477,057. C. B. Grady, Jr. Iss. 7/26/49. App. 1/11/46. Assign. Celanese Corp. of America.

Apparatus for Detecting Metal Particles. A system for detecting metal particles on a conveyor belt and in which the belt passes through a verticle loop excited by an oscillator and the field distortion picked up by a symmetrically placed horizontal loop whose signal is amplified.

U. S. No. 2,477,971. H. C. Drake. Iss. 8/2/49. App. 3/8/44. Assign. Sperry Products, Inc.

Rail Flaw Detector Mechanism. A rail flaw detector in which the leading pickup coil and the trailing pickup coil have independent amplifying channels whose outputs are connected to a differential relay so that sudden pulses in both coils maintain the recorder inoperative while a pulse in the trailing coil alone effects a record.

U. S. No. 2,478,842. T. F. Schwartz and A. L. Giorgi. Iss. 8/9/49. App. 1/19/45.

Submarine Radiation Apparatus and Photographic Method. An apparatus for making X-ray photographs of submarine structures and having the X-ray equipment in a tank with an air cell between the X-ray tube and the structure, the air pressure being automatically adjusted for depth of immersion.

U. S. No. 2,478,951. J. M. Stokely and G. M. Cook. Iss. 8/16/49. App. 5/23/44. Assign. California Research Corp.

Flaw Detection Fluid. A liquid which shows up defects in a metal surface in daylight consisting of a penetrating mineral oil, an emulsifier and a light-reflecting dye such as rhodamine.

U. S. No. 2,479,219. H. C. Drake, Iss. 8/16/49. App. 9/20/45. Assign. Sperry Products, Inc.

Rail Flaw Detector Car Mechanism. A rail flaw detector in which current is applied to the rail by brushes and distortion of the field detected, the apparatus being automatically lifted off the rail when it is not in motion so as to avoid interfering with block-signal operation.

U. S. No. 2,481,858. W. E. Mesh. Iss. 9/13/49. App. 3/2/48. Assign. Sperry Products, Inc.

Rail Flaw Detector Mechanism. A rail flaw detector in which current is applied to the rail and magnetic distortion detected, the current brushes being far enough apart so that the pulse generated when a brush passes a rail joint is of low frequency while brush contact chatter is of high frequency and is filtered out.

148—FLOW METER

U. S. No. 2,475,630. W. Melas and W. B. Heinz. Iss. 7/12/49. App. 9/12/44. Assign. Penn Industrial Instrument Corp.

Flow meter. A remote indicating rotameter-type flow meter in which the float carries a magnet which draws along an iron follower in an adjacent tapered tube through which air is forced and its pressure indicated.

U. S. No. 2,476,163. H. A. Trebler. Iss. 7/12/49. App. 5/15/44. Assign. National Dairy Research Laboratories, Inc.

Continuous Automatic Sampling of Liquids in Proportion to the Flow. A sampling device having a motor-driven wheel with a scoop which dips up a sample of liquid flowing in a weir box, the amount dipped up being proportional to the depth of liquid flowing over the weir notch.

U. S. No. 2,479,786. D. S. Stevens. Iss. 8/23/49. App. 10/24/45.

Liquid Flow Gauge. An all glass flow meter having an open U-tube with the liquid entering one arm and with a small orifice in the side of the other arm and a scale so that the fluid height above the orifice may be observed.

U. S. No. 2,480,646. W. C. Grabau. Iss. 8/30/49. App. 1/17/45. Assign. Raytheon Manufacturing Co

Speed Measuring Device. An air-speed meter or flow meter having a source of continuous sound waves which are simultaneously picked up at points having different directions from the source and the phase difference of the picked-up signals observed and indicated as velocity.

U. S. No. 2,483,190. J. R. Evans. Iss. 9/27/49. App. 8/6/45.

Flow Meter. A flow meter having an impeller suspended on a torsion spring inside a transparent section of pipe with rotational displacement of the impeller read on a scale on the transparent pipe.

160—GALVANOMETER

U. S. No. 2,478,625. H. T. Faus and L. F. Perotte. Iss. 8/9/49. App. 8/31/48. Assign. General Electric Co.

Thermomagnetic Galvanometer. A galvanometer which has a spring-biased nonmagnetic armature wound with an alloy wire whose permeability changes with temperature, so that the angle between the wire and the field changes due to heating of the wire by the current flowing through it.

172—GEOCHEMICAL PROSPECTING

U. S. No. 2,479,787. N. P. Stevens. Iss. 8/23/49. App. 12/23/44. Assign. Socony-Vacuum Oil Co., Inc.

Geophysical Prospecting Method. A soil gas prospecting method in which gas is withdrawn from a hole below the soil-breathing level and analyzed for oxygen and carbon dioxide, petroleum being indicated by an increase in oxygen-carbon dioxide ratio.

180—GRAVIMETER

U. S. No. 2,477,927. R. A. Hanson. Iss. 8/2/49. App. 2/4/48.

Level Sensitive Switch. An endless closed tube in the shape of a rectangle with contacts in pockets on the vertical sides and a conducting liquid in the bottom tube which also has a capillary constriction.

188—HYGROMETER

U. S. No. 2,480,983. P. O. Unger. Iss. 9/6/49. App. 2/14/47. Assign. Autopoint Co.

Hygroscopic Coil for Humidity Indicators. A mechanically-indicating hygrometer having a coiled metal strip to one side of which a hygroscopic absorbent material is sewed by an absorbent thread.

U. S. No. 2,481,332. F. B. Newell and V. E. Matner. Iss. 9/6/49. App. 12/10/47. Assign. Taylor Instrument Companies.

Hygrometer. A wet and dry bulb hygrometer in which an upward-extending wick on the wet-bulb thermometer is automatically kept moistened by a motor-driven scoop which delivers the water at the top of the wick so that after evaporation it trickles over the bulb.

U. S. No. 2,481,728. A. B. Dember. Iss. 9/13/49. App. 10/24/45. Assign. Bendix Aviation Corp.

Humidity Responsive Resistor. An electric hygrometer having two electrodes mounted as adjacent strips on an insulating backing and with hygroscopic material between them, the edges of the electrodes being turned up to provide a large area of contact.

192—INCLINOMETER

U. S. No. 2,479,377. F. Lenzen and J. G. Jackson. Iss. 8/16/49. App. 10/25/46. Assign. Eastman Oil Well Survey Co.

Inclination Indicating Instrument. A pendulum inclinometer having a stylus on the end of a pendulum and a record disk which is moved against the stylus by a clock.

U. S. No. 2,482,224. J. S. Swearingen. Iss. 9/20/49. App. 11/30/40. Assign. Robinson Tool Co.

Clinometer for Well Bores. An inclinometer for use while drilling and concentrically mounted in the drill collar with a fluid by-pass and arranged so that when circulation is stopped a pendulum catches on steps of a spring-actuated plunger connected to a valve, the valve causing pressure signals as it passes constrictions in the drill collar indicating the step when circulation is resumed.

200—LEVEL INDICATOR

U. S. No. 2,477,511. D. M. Comb. Iss. 7/26/49. App. 6/4/48.

Liquid Level Control. A liquid level gauge having a condenser whose capacity is changed by the liquid between its plates and connected in a bridge circuit with a grid-glow tube as indicator.

U. S. No. 2,483,266. C. A. de Giers. Iss. 9/27/49. App. 9/8/45. Assign. The Liquidometer Corp.

Electron Tube Type Transmitter. A level indicator in which a float moves a magnet surrounding an electron beam tube to vary the position of impingement of the beam on a resistor in the tube.

208—LOGGING WHILE DRILLING

U. S. No. 2,482,165. W. R. Flatford. Iss. 9/20/49. App. 9/9/44. Assign. Phillips Petroleum Co.

Signal Generator. A device which may be dropped through the drill stem for supplying a-c to the drill and having batteries which drive a vibrator actuating a ratchet which closes a switch by the time the device gets on bottom and connects the a-c output of the vibrator to the drill.

216—MAGNETIC COMPASS

U. S. No. 2,475,593. R. V. Craddock and R. S. Curry, Jr. Iss. 7/12/49. App. 8/28/45. Assign. The Sperry Corp.

Self-Synchronous Flux Valve System. A three-legged flux-valve compass in which the indicator is excited by the same source which excites the flux valve and with a frequency-halving circuit between the flux valves and the stator of the indicator.

U. S. No. 2,479,562. T. M. Ferrill, Jr. Iss. 8/23/49. App. 8/2/46. Assign. The Sperry Corp.

Reference Apparatus. A magnetic direction indicator having a stretched wire kept in sustained vibration in the earth's field and its direction of vibration detected by the high-frequency component induced by quadrature coils excited at different frequencies.

224—MAGNETIC RECORDER

U. S. No. 2,475,421. M. Camras. Iss. 7/5/49. App. 5/30/45. Assign. Armour Research Foundation of Illinois Institute of Technology.

Combined Erasing and Recording Magnetic Transducer. An erasing and recording head for a magnetic recorder having an E-shaped core with the recording coil on one outer leg and an a-c erasing coil on the other outer leg and with a few turns of the erasing circuit around the recording leg.

U. S. No. 2,475,694. M. Camras. Iss. 7/12/49. App. 3/29/44. Assign. Armour Research Foundation of Illinois Institute of Technology.

Nontwisting Paramagnetic Record Wire. A round magnetic record wire having a permanent preset curvature so as to prevent twisting when it travels from one spool to the other.

U. S. No. 2,475,742. J. H. Hammond, Jr. Iss. 7/12/49. App. 4/17/46.

Apparatus for Producing Reentrant Magnetic Records. An apparatus for making an endless magnetic record on a rotating disc in which the signal from a monitoring pickup is synchronized with the recording signal by comparison on a c-r tube so that the recording speed may be adjusted to give an endless record.

U. S. No. 2,476,110. J. Neufeld. Iss. 7/12/49. App. 9/8/44.

Transducing System to Compensate for Torsion in a Magnetic Record Wire. A magnetic reproducing head having two pairs of pickup coils at right angles with their signals added arithmetically by means of two ring modulators.

U. S. No. 2,476,599. W. J. Haloski. Iss. 7/19/49. App. 8/23/45. Assign. Armour Research Foundation of Illinois Institute of Technology.

Magazine Type Magnetic Recording Apparatus. A magnetic recorder magazine which has two reels and a pair of pole pieces over which the wire travels, the pole pieces engaging a wound magnet on the frame of the recorder when the magazine is put in place.

U. S. No. 2,477,144. S. A. Scherbatskoy. Iss. 7/26/49. App. 2/18/43.

Combined Recorder and Reproducer. A magnetic recorder for recording and reproducing longitudinally on a fine wire and which introduces an equalizing circuit in series with the speaker when used for recording and an integrator circuit when used for reproducing.

U. S. No. 2,477,146. S. A. Scherbatskoy. Iss. 7/26/49. App. 3/23/45.

Combined Recording and Reproducing. A magnetic wire recorder in which the wire leaves the storage spool, goes around a driving pulley and onto a take-up spool, the storage spool and take-up spool being on the same shaft and elastically connected by a helical spring on the shaft.

U. S. No. 2,479,308. M. Camras. Iss. 8/16/49. App. 3/17/45. Assign. Armour Research Foundation of Illinois Institute of Technology.

Magnetic Recorder Head. A magnetic recorder head in which the magnetic circuit is energized by a single transverse conductor which is connected as a single turn through a matching transformer.

U. S. No. 2,479,551. N. B. Blake. Iss. 8/23/49. App. 9/12/46. Assign. Sun Oil Co.

Harmonic Generator. A harmonic generator in which the amplified output of a tuning fork is applied to a gas-filled rectifier with a resistor and evacuated diode in parallel, the tubes being biased in opposite directions.

U. S. No. 2,480,742. E. L. Kent. Iss. 8/30/49. App. 5/30/45. Assign. C. G. Conn, Ltd.

Magazine Type Magnetic Recording Apparatus. A magnetic recorder having a large constant-speed take-up reel and a closed type head into which the record wire may be inserted by opening a switch in a single-turn pickup circuit.

U. S. No. 2,481,004. C. B. Dale. Iss. 9/6/49. App. 6/19/47. Assign. Webster-Chicago Corp.

Wire Recorder. A magnetic wire recorder having automatically-operated brakes on the take-up and on the supply spools so that the wire is always kept taut.

U. S. No. 2,481,393. M. Camras. Iss. 9/6/49. App. 5/30/45. Assign. Armour Research Foundation of Illinois Institute of Technology.

Magnetic Recording Head. A magnetic recording head whose pole pieces have a groove which is shallow at the pole tips to give high flux density and which gradually becomes deeper away from the pole tips so as to keep the wire from slipping out of the groove.

U. S. No. 2,481,904. M. Camras. Iss. 9/13/49. App. 3/17/45. Assign. Armour Research Foundation of Illinois Institute of Technology.

Bifilar Magnetic Recording System. A magnetic recorder using two wires on two sets of reels and two sets of recording, erasing and reproducing heads, so that one wire may be used for recording while the other is rewinding.

U. S. No. 2,482,887. W. H. Wade. Iss. 9/27/49. App. 10/25/45. Assign. Lear, Inc.

Drive System for Magnetic Recorders. A drive system for a magazine-type magnetic recorder having a drive shaft with a pair of worms which are shiftable to engage either one of the reels.

U. S. No. 2,483,123. C. W. Clapp. Iss. 9/27/49. App. 11/2/44. Assign. General Electric Co.

Humbucking Arrangement for Magnetic Transducers. A magnetic recorder head whose magnetic core is in two parts with two air gaps in series and having coils wound on both parts of the core.

228—MAGNETIC TESTING

U. S. No. 2,477,384. E. R. Mann and H. E. Beste. Iss. 7/26/49. App. 11/9/43. Assign. Allen B. Du Mont Laboratories, Inc.

Cyclograph for Testing Metals. A core-loss testing apparatus in which the specimen is placed in a coil excited by a modulated audio frequency which is demodulated and mixed with a portion of the original modulating signal and the mixer adjusted for balance.

U. S. No. 2,478,772. M. L. Mages and H. T. Nordstrom. Iss. 8/9/49. App. 10/18/44. Assign. Magnaflux Corp.

Method and Apparatus for Magnetic Inspection. A magnetic testing method in which the specimen is magnetized between pole pieces arranged so that asymmetric magnetization is produced and flaws detected by applying iron particles to the surface.

U. S. No. 2,478,773. R. De O. McDill. Iss. 8/9/49. App. 6/21/43. Assign. Thompson Products, Inc.

Magnetic Measuring Device and Method. A method of magnetically measuring the head-wall thickness of a sodium-filled valve by driving the sodium into the head and then applying the valve head as the armature of a coil excited at a frequency high enough so that eddy currents do not penetrate through the wall and measuring the change of induction of the coil.

U. S. No. 2,479, 699. W. M. Powell. Iss. 8/23/49. App. 8/9/46. Assign. U. S. A.

Apparatus for Magnetic Measurements. A flux meter calibrating device having a coil which is allowed to fall over a cylindrical magnet and with taps on the coil to provide a series of calibration points.

U. S. No. 2,481,345. M. F. Reynst. Iss. 9/6/49. App. 6/7/41 and 5/9/46. Assign. Hartford National Bank and Trust Co.

Device for Magnetically Determining Thickness of Coatings. Apparatus for testing the thickness of non-magnetic coatings on magnetic material by having the material complete the magnetic circuit of an E-shaped core connected in an a-c bridge circuit, the center leg of the E having a screw which may be adjusted to compensate for various materials.

U. S. No. 2,481,937. M. L. Mages. Iss. 9/13/49. App. 6/21/43. Assign. Magnaflux Corp.

Magnetic Testing System. A system for magnetizing articles to be dusted with paramagnetic particles, d-c power being obtained from transformers and rectifiers and the magnetizing current cut off by rapidly opening first the transformer primary circuit and then the d-c circuit.

232—MAGNETOMETER

U. S. No. 2,476,273. L. F. Beach. Iss. 7/19/49. App. 9/17/42. Assign. Purves Corp.

Apparatus Sensitive to Magnetic Fields. A flux-valve having two cores carrying opposed primary windings with a single secondary winding about both and arranged so that the effect of the primary excitation can be balanced out either by changing the relative exciting currents, changing the relative lengths of the cores or by shifting part of the primary windings from one core to the other.

U. S. No. 2,477,337. W. E. Kahl. Iss. 7/26/49. App. 7/31/44. Assign. Bell Telephone Laboratories, Inc.

Magnetic Detector. A second-harmonic flux-valve magnetic detector which is insensitive to variations in exciting voltage and having a series-connected condensor to approximately tune the winding at the fundamental frequency and a shunt resistance approximating the effective resistance of the network.

U. S. No. 2,480,265. J. H. Rubenstein. Iss. 8/30/49. App. 1/23/46.

Magnetometer. A magnetometer or compass element in which the inductor core and its pole pieces are dimensioned so that when the core approaches saturation the pole pieces are approaching maximum permeability.

236—MASS SPECTROMETRY

U. S. No. 2,475,653. H. W. Washburn. Iss. 7/12/49. App. 4/28/45. Assign. Consolidated Engineering Corp.

Mass Spectrometry. A mass spectrometer in which the gas flows through a slit in the inlet electrode with a transverse slot lengthwise of the slit and with the electron beam traversing the gas as it passes through the slit.

U. S. No. 2,476,005. B. W. Thomas. Iss. 7/12/49. App. 8/6/45. Assign. Standard Oil Development Co.

Analytical Apparatus. A mass spectrometer in which a fixed portion of the ion signal is used to vary the response of the recorder inversely as the intensity of the beam.

248—MOTION TESTING

U. S. No. 2,479,808. R. A. Beth. Iss. 8/23/49. App. 3/28/47. Assign. U. S. A.

Electromagnetic Apparatus for Measuring Projectile Velocity During Penetration. Apparatus for measuring the position of a magnetized projectile as a function of time as it penetrates a non-magnetic target and having coils on both sides of the target connected in opposition and indicating the induced voltage on a c-r tube with time-controlled sweep.

276—PERMEABILITY TESTING

U. S. No. 2,475,353. H. G. Doll. Iss. 7/5/49. App. 6/13/42 and 10/8/47. Assign. Schlumberger Well Surveying Corp.

Well Surveying Apparatus. Apparatus for generating a fluctuating pressure opposite a formation by a motor which revolves eccentric weights in the well apparatus and measuring the a-c component of the electrofiltration potential.

U. S. No, 2,475,354. H. G. Doll. Iss. 7/5/49. App. 6/13/42 and 10/8/47. Assign. Schlumberger Well Surveying Corp.

Well Logging Equipment. Apparatus for generating a fluctuating pressure opposite a formation by a motor-driven cam which expands and contracts a Sylphon bellows in the well apparatus and measuring the a-c component of the electrofiltration potential.

288—PRESSURE GAUGE

U. S. No. 2,477,026. E. Wenk, Jr. and R. S. Thatcher. Iss. 7/26/49. App. 9/20/46.

Electric Fluid Pressure Gauge. A pressure gauge having a cylinder with a partition and a filament-type strain gauge wound around the cylinder on the pressure side of the partition and a similar gauge wound around the cylinder on the free end of the cylinder so as to compensate for temperature variations.

U. S. No. 2,477, 233. C. W. Bristol. Iss. 7/26/49. App. 10/9/44. Assign. The Bristol Co.

Apparatus for Measuring Absolute Pressure. An absolute pressure gauge having two small-diameter bellows in opposition with a spring and larger bellows around one of them and an indicator extending through the other.

U. S. No. 2,477,507. A. Africano. Iss. 7/26/49. App. 8/2/45. Assign. U. S. A.

Electrical Pressure Gauge. A pressure gauge shaped like a grease cup and filled with grease and having a filament type strain gauge on a diaphragm in the cover.

U. S. No. 2,481,651. J. T. Fitzpatrick. Iss. 9/13/49. App. 4/5/45.

Pressure Indicating Device. A gauge for indicating maximum value of a pulsating pressure and have a piston sliding in a cylinder one side of which is connected to an indicating gauge by liquid and the other side of which is connected to the source of pressure through a check valve.

U. S. No. 2,483,300. W. H. Howe. Iss. 9/27/49. App. 6/6/45. Assign. The Foxboro Co.

Interchangeable Electrical Condition Responsive Unit. A pressure gauge unit having a hollow tube whose interior is exposed to the pressure and with two filament-type strain gauges wound on its outer surface, and also having a similar solid rod with temperature-compensating filaments wound on it, the filaments being connected in a bridge circuit and the unit provided with a four-prong plug for connecting to an external source of power and indicator.

U. S. No. 2,483,384. A. A. Hejduk. Iss. 9/27/49. App. 7/26/44. Assign. The Meriam Instrument Co.

Multiple Well Manometer. A manometer having two tubes with the well of one at a low level and exposed to the pressure to be measured and the well of the other at a high level with the tube exposed to the pressure so that low pressure readings on the first tube are adjacent to high pressure readings on the second tube.

304—RADIOACTIVITY LOGGING

U. S. No. 2,475,137. G. Herzog. Iss. 7/5/49. App. 3/21/45. Assign. The Texas Co.

Radiological Well Logging. A radioactivity well logging system using a source of neutrons and gamma rays and simultaneously measuring the intensity of gamma rays liberated by neutrons in the formation, scattered gamma rays plus liberated gamma rays and scattered neutrons, the gamma ray detectors being adjacent to the source above and below it and the neutron detector being horizontally opposite to the source.

U. S. No. 2,480,674. W. L. Russell. Iss. 8/30/49. App. 4/13/44. Assign. Well Surveys Inc.

Neutron Method of Porosity Logging. A method of determining permeability and porosity of formations by running a neutron log, forcing boric acid into the formations and running successive neutron logs as the material penetrates the formations.

U. S. No. 2,481,014. G. Herzog. Iss. 9/6/49. App. 3/22/45. Assign. The Texas Co.

Method and Apparatus for Radioactivity Well Logging. A radioactivity logging apparatus having a long radiation detector and a shorter detector whose length is about the same as the thickness of a thin stratum, and recording the output of the short detector when logging thin strata and the output of both detectors in other portions of the hole.

U. S. No. 2,483,139. G. Herzog. Iss. 9/27/49. App. 12/31/43. Assign. The Texas Co.

Method and Apparatus for Logging Boreholes. A neutron logging system using a mixture of radium and beryllium as a source of neutrons and gamma rays, and detecting scattered slow neutrons by measuring only large pulses in a proportional counter adjacent to the source.

308—RADIOACTIVITY MEASUREMENTS

U. S. No. 2,475,603. H. Friedman. Iss. 7/12/49. App. 3/5/46.

Geiger Counter Structure. A Geiger-Muller counter whose envelope has a thin window and a linear anode pointing toward the window and a helical cathode of small pitch concentric with the anode.

U. S. No. 2,475,988. A. E. Rodd. Iss. 7/12/49. App. 11/8/48. Assign. Bradford Novelty Co., Inc.

Ionization Gauge Having an Exchangeable Filament. An ionization gauge unit which may be inserted into a vacuum system and which has guide posts and arms for holding a replaceable filament.

U. S. No. 2,476,810. E. N. Brunner and E. S. Mardock. Iss. 7/19/49. App. 4/10/45. Assign. Shell Development Co.

Method and Apparatus for Radiological Measurements. A method of determining hydrogen inside a closed container by irradiating the container and also an adjacent absorbing material with fast neutrons for a time, then removing the neutron source and waiting for slow-neutron-induced activity of the absorbing material to subside and subsequently measuring the activity of the absorbing material.

U. S. No. 2,479,201. J. Bleeksma. Iss. 8/16/49. App. 1/31/44. Assign. Philips Laboratories, Inc.

Geiger-Muller Counter. A Geiger-Muller counter having a cylindrical metal cathode forming the case and a metal-to-glass seal at one end for holding the anode and a glass seal with a radiation window at the other end.

U. S. No. 2,479,271. F. R. Shonka. Iss. 8/16/49. App. 11/21/46. Assign. U. S. A.

Ionization Chamber Circuit. An ionization chamber having an inverted cup forming one electrode and a smaller concentric cup forming the other electrode, and inside the inner cup a partially shielded source of beta particles whose position may be adjusted to produce a current through the chamber which neutralizes the grid current of the associated vacuum tube.

U. S. No. 2,479,882. C. W. Wallhausen, H. H. Dooley and C. C. Carroll. Iss. 8/23/49. App. 3/14/46. Assign. U. S. Radium Corp.

Radioactive Metal Products and Method for Manufacturing. An alpha particle source made by incorporating a finely-divided radioactive material in a thin metal film with a non-radioactive metal film on one side and a thick backing on the other side.

U. S. No. 2,480,846. H. Friedman and L. Wolfe. Iss. 9/6/49. App. 1/16/45.

Ice Detector. A wing ice warning device having a source of penetrating radiation held in front of the wing with a Geiger-Muller counter inside the wing connected to a quenching circuit, amplifier, and counting-rate meter.

U. S. No. 2,481,506. C. C. Gamertsfelder, Jr. Iss. 9/13/49. App. 7/6/44. Assign. U. S. A.

Fast Neutron Meter. A neutron counter having a central electrode surrounded by an electrically-conducting container of argon under pressure and this in turn surrounded by an electrically-conducting container of methane under pressure and electrically connected to the central electrode, the gas pressures being adjusted so that the ionization current due to gamma rays cancels out.

U. S. No. 2,481,964. E. O. Wollan. Iss. 9/13/49. App. 10/12/44.

Fast Neutron Meter. A neutron counter using two ionization chambers whose center electrodes are connected together and with opposite polarities on the outer electrodes, one chamber being filled with a gas ionizable by gamma rays but not by neutrons and the other filled with a gas ionizable by both gamma rays and neutrons.

312—RADIO NAVIGATION

U. S. No. 2,477,145. S. A. Scherbatskoy. Iss. 7/26/49. App. 2/22/45.

Navigational Method and Apparatus. A radio navigation system using two broadcast stations and in which the mobile craft carries a radio direction finder which is automatically tuned to the stations in repeated succession and the position of the craft with respect to a line through the two stations indicated.

U. S. No. 2,478,833. W. J. O'Brien. Iss. 8/9/49. App. 6/3/46. Assign. The Decca Record Co., Ltd.

Area Identification System. A radio navigation system in which three fixed stations radiate frequencies having a harmonic relationship and maintained at a multiple phase relationship so that the receiving apparatus can identify the in-phase lanes in the field.

U. S. No. 2,479,531. J. T. Webber. Iss. 8/16/49. App. 1/24/45. Assign. Editors and Engineers, Ltd.

Position Indicating System. A radio position indicator using three transmitting stations with over-lapping fields, and each radiating four lobes, and with each station transmitting relatively short pulses at slightly different rates, the receiver being arranged so that coincidence of pulses produces a radial line on a c-r tube screen.

U. S. No. 2,479,567. L. b. Hallman, Jr. Iss. 8/23/49. App. 2/11/41. Assign. U. S. A.

Radio Position Determining System. A blind landing system having three frequency-modulated beams radiated from ground points and two receivers on the plane each detecting and indicating the beat note between two of the beams.

U. S. No. 2,480,068. I. Wolff. Iss. 8/23/49. App. 8/9/46. Assign. Radio Corp. of America.

Radio Navigation Aid. A blind landing system having two radar stations on the ground scanning in azimuth and elevation respectively and with their indications transmitted to the plane by television.

U. S. No. 2,480 123. E. M. Deloraine and P. R. Adams. Iss. 8/30/49. App. 4/29/44 and 12/15/45. Assign. Federal Telephone and Radio Corp.

Aircraft Flight Indicating System. An aircraft guiding and traffic control system using towers between which UHF communication is maintained and which may be used as radio beacons along an air lane.

U. S. No. 2,480,208. L. W. Alvarez. Iss. 8/30/49. App. 6/27/44. Assign. U. S. A.

Radio Distance and Direction Indicator. A radio navigation system in which a radar apparatus on the plane produces on a c-r tube screen a map-like representation of reflecting objects on the ground.

U. S. No. 2,480,875. W. J. O'Brien. Iss. 9/6/49. App. 3/20/47 and 3/20/48. Assign. The Decca Record Co., Ltd.

Navigation System. A radio navigation system of the phase-comparison type in which three harmonically-related frequencies are transmitted from three points and in which a fine sensitivity field pattern and a coarse sensitivity field pattern are produced by having one of the transmitters emit a fourth frequency related to the sum and difference of the other two.

U. S. No. 2,482,105. L. G. Duggar. Iss. 9/20/49. App. 3/5/45.

Navigational System. A radio-navigation system using Selsyn connections between two rotatable loops and two indicators, the stators of the loop Selsyns being mounted on the rotors of separate Selsyn-controlled compass repeaters.

U. S. No. 2,482,809. H. H. Thompson. Iss. 9/27/49. App. 4/8/48. Assign. The Sperry Corp.

Radio Craft Guidance System. A radio guidance system for automatically holding a craft on a radio course in the presence of cross wind in which the initial course displacement is integrated for a time and the heading of the craft corrected so that no course displacement occurs.

316—RADIO RANGING

U. S. No. 2,474,875. G. E. White. Iss. 7/5/49. App. 1/22/43. Assign. The Sperry Corp.

Pulse Echo Volume Compensating System. A radio pulse echo system in which the gain of the receiver is increased during the gating period so as to compensate for attenuation of more distant reflections.

U. S. No. 2,475,004. E. D. Blodgett. Iss. 7/5/49. App. 3/22/47. Assign. Radio Corp. of America.

Radio Direction Finding. A radio direction finding system using four antennas at the corners of a square and in which the received signals are transmitted to the center of the square by ultra-high frequency radio so as to eliminate erros caused by the presence of horizontal feeders.

U. S. No. 2,475,190. L. Levy. Iss. 7/5/49. App. 5/13/38 and 5/6/39. Vested in the Attorney General of the U. S.

Radio Direction Finder. A radio direction finder in which a loop is rotated by a motor which also drives double-frequency generators for exciting quadrature field coils of an indicator whose moving coil is connected to the loop through a superheterodyne receiver.

U. S. No. 1,475,412. E. Torcheux. Iss. 7/5/49. App. 2/14/42 and 11/19/45. Assign. Société Française Radio Électrique.

Radio Direction Finder. A radio direction finder using a directional loop antenna and a non-directional antenna and linearly combining their signals to obtain potentials which are compared with the signals from the non-directional antenna.

U. S. No. 2,475,598. G. J. Eltz. Iss. 7/12/49. App. 2/25/43.

Means for Determining Range. A radio ranging indicator in which a neon tube is flashed by the transmitted and received pulses and the travel time indicated on a screen by passing the light through a slit moved in synchronism with the pulsing oscillator.

U. S. No. 2,475,612. P. G. Hansel. Iss. 7/12/49. App. 6/27/45.

Direction Finding System. A radio direction finding system in which a low-frequency signal is produced whose phase is a function of the direction and this signal also controls the beam intensity of a c-r indicating tube so that the signal stands out against background noise.

U. S. No. 2,475,707. P. A. Jeanne. Iss. 7/12/49. App. 2/24/44 and 3/19/45. Assign. Bell Telephone Laboratories, Inc.

Object Locator System. A radio ranging system in which the reflected pulse is indicated on a c-r tube screen with part of the time scale expanded by increasing the rate of discharge of the sweep capacitor.

U. S. No. 2,476,409. A. L. Free. Iss. 7/19/49. App. 3/6/46. Assign. Philco Corp.

Automatic Regeneration Control for Pulse-Echo Systems. A radio ranging system using a super-regenerative receiver which is unquenched by coincidence of a reflection and a quench oscillator pulse.

U. S. No. 2,476,977. P. G. Hansel. Iss. 7/26/49. App. 6/24/44.

Radio Direction Finder. A radio direction finder using four omnidirectional antennas whose outputs are differentially modulated at audio frequency and combined in a common impedance so that the envelope phase is a function of the bearing.

U. S. No. 2,477,434. W. H. Wirkler. Iss. 7/26/49. App. 12/9/47. Assign. Collins Radio Co.

Radio Direction Finding. A radio direction finder using a loop and a non-directional antenna with the signal from the loop modulated in a balanced modulator and fed to a superheterodyne receiver with the signal from the antenna, the output being detected and applied to a product detector together with signal from the local oscillator.

U. S. No. 2,479,489. G. Guanella. Iss. 8/16/49. App. 10/16/39 and 9/3/47. Assign. Radio Patents Corp.

Direct Reading Radio Direction Finder. A radio direction finder using two loops and a non-directional antenna, the signals from the loops being commutated and combined with that of the antenna, amplified, rectified, and applied to the crossed filed coils of a rotary indicator.

U. S. No. 2,479,892. J. Aicardi. Iss. 8/23/49. App. 10/27/44 and 7/3/45. Assign. Sadir-Carpentier.

Radio Direction Finder. A radio direction finder using two spaced antennas whose signals are beat against that of a local oscillator and the phases of the beat signals compared.

U. S. No. 2,480,152. M. Mandel. Iss. 8/30/49. App. 7/2/46. Assign. Federal Telecommunication Laboratories, Inc.

Position Indicating System. A system for indicating the position of a mobile transmitter by receiving its signal at three spaced points and indicating on a c-r tube screen radial lines to the transmitter from three points on the screen representing the receiver locations.

U. S. No. 2,480,201. W. Selove. Iss. 8/30/49. App. 5/8/46. Assign. U. S. A.

Apparatus for Compressing the Amplitude Range of Signals. A circuit for reducing the over-all range of signals which are to be fed to a differentiating circuit by using a network of four amplifier tubes which are successively brought into operation as the signal amplitude increases and interconnected so that the output first increases, then decreases and finally increases with increasing amplitude of input.

U. S. No. 2,480,234. E. G. Gage. Iss. 8/30/49. App. 5/3/46. Assign. Two-Thirds to Leon Ottinger.

Cathode-Ray Direction Finder. A radio direction finder using four directional antennas whose outputs are successively used to deflect a c-r tube spot in a line indicating the antenna direction and whose length is proportional to the signal amplitudes.

U. S. No. 2,480,842. N. B. Farnsworth. Iss. 9/6/49. App. 3/6/45. Assign. The Sperry Corp.

Automatic Gain-Control System. An avc network for a radar scanner in which the filter has two series resistors whose junctions are grounded through a condenser and which are shunted by a condenser adjusted so as to eliminate phase shift at the output of the amplifier.

U. S. No. 2,483,187. C. E. Dolberg. Iss. 9/27/49. App. 8/30/44. Assign. Philco Corp.

Pulse Radio Echo Distance Indicator. A radar system in which pulses from the transmitter-control circuit are delayed slightly and introduced into the receiver frequency-converter stage as a neutralizing voltage to cancel leakage pickup of the transmitted pulses in the receiver.

324—RECORDER

U. S. No. 2,475,387. S. Golden. Iss. 7/5/49. App. 11/2/45. Assign. U. S. A.

Ordnance Pressure Time Recorder. A system for recording the pressure-time characteristic of a mortar by having a pressure gauge control the displacement of a c-r tube spot and photographing it with a moving film camera, the c-r spot being held off the screen before and after firing by projectile-controlled circuits.

U. S. No. 2,477,062. E. Jacobi. Iss. 7/26/49. App. 3/2/39 and 10/28/41. Vested in Attorney General of the U. S.

Apparatus for Recording of Rapidly Varying Processes. An electrolytic or spark recorder in which a stylus is rapidly moved across the tape and the voltage on a thyratron synchronously increased and arranged so that when the thyratron fires it impresses a voltage on the stylus to make a mark.

U. S. No. 2,477,640. H. R. Montague. Iss. 8/2/49. App. 6/27/44.

Sound Recording Method and Apparatus. A system for making a sound record by radially modulating a c-r tube trace which executes a spiral path and photographically recording on a disc placed against the end of the tube.

U. S. No. 2,478,538. R. G. Leitner. Iss. 8/9/49. App. 9/30/42. Assign. Frank Rieber.

Sound Translating Device. A phonograph recorder in which the record remains stationary so that legends on it can be read and the stylus head moves in a spiral path to follow the sound groove.

U. S. No. 2,478,539. R. G. Leitner. Iss. 8/9/49. App. 1/18/43. Assign. Frank Rieber.

Spiral Sound Record Strip. A phonograph record in the form of a wide strip with a succession of spiral-groove sound records and printed legends, the records being played on a rotating-stylus recorder.

U. S. No. 2,479,640. W. K. Rieber. Iss. 8/23/49. App. 10/12/45.

Phonographic Apparatus. A phonograph recorder having a brake which is automatically engaged when shifting from record cutting to reproducing so as to equalize the motor load.

U. S. No. 2,480,443. E. H. Branson. Iss. 8/30/49. App. 10/3/45. Assign. General Railway Signal Co.

Recorder Actuated by Electrically Heated Wires. A multi-pen strip recorder in which the pens are carried by pivoted blocks which are connected to a support by two fine wires one of which carries the recording current.

U. S. No. 2,482,212. W. K. Rieber. Iss. 9/20/49. App. 12/22/45.

Combined Recording and Reproducing Device. A phonograph recorder having a recording head and a reproducing head mounted on a turret so that either one may be placed in contact with the record, the turret operating a switch which connects the amplifier to the head being used.

332—SEA SAMPLER

U. S. No. 2,477,094. R. F. Shropshire. Iss. 7/26/49. App. 5/2/45. Assign. Raytheon Manufacturing Co.

Underwater Bottom Hardness Tester. A device which may be dropped through the water on a line for measuring the hardness of the bottom and having on its lower end a foot on a spring whose maximum compression on impact is indicated by a rider.

344—SEISMOGRAPH AMPLIFIER

U. S. No. 2,482,849. G. J. L. Guyot and P. Gillet. Iss. 9/27/49. App. 10/16/46 and 12/5/47.

Method and Means for Measuring the Microphonic Action of Multielectrode Tubes. A method of testing a vacuum tube for microphonics by subjecting it to sound of different frequencies and comparing the variations in tube current with the sound.

356—SEISMOGRAPH MIXING

U. S. No. 2,477,844. A. Wolf. Iss. 8/2/49. App. 4/20/43 and 4/25/27. Assign. Texaco Development Corp.

Seismic Exploration with Control of Directional Sensitivity. A seismograph mixing system in which sensitivity to reflections from steeply-dipping beds is accentuated by grounding one side of each geophone and connecting the other side to ground through a large impedance and a small impedance in series, the amplifiers being connected across pairs of the small impedances.

360—SEISMOGRAPH PROSPECTING

U. S. No. 2,479,772. G. Peterson. Iss. 8/23/49. App. 7/29/48. Assign. Phillips Petroleum Co.

Method of and Apparatus for Geophysical Exploration. A method of determining time delays in a seismograph system using radio recording by recording a radio signal and a simultaneous mechanical shock applied to the geophone by a relay actuated from the control point.

372—SEISMOGRAPH VOLUME CONTROL

U. S. No. 2,475,258. C. B. Scott. Iss. 7/5/49. App. 4/4/46. Assign. Standard Oil Development Co.

Feedback Automatic Volume Control Circuit for Seismic Amplifiers. An avc circuit for seismograph amplifiers in which amplifier output signal is applied in push-pull to a transformer in the cathode circuit of an earlier stage.

U. S. No. 2,476,990. F. P. Mason. Iss. 7/26/49. App. 1/5/44 and 12/15/44. Assign. Creed and Co. Ltd.

Automatic Gain Control. An avc circuit for a telegraph amplifier in which a push-pull output is used to charge condensers through rectifiers and discharge through tubes which are controlled by the amplitude of the next half cycle, the difference in the condenser voltages being used to control the amplifier.

U. S. No. 2,480,201. W. Selove. Iss. 8/30/49. App. 5/8/46. Assign. U. S. A.

Apparatus for Compressing the Amplitude Range of Signals. A circuit for reducing the over-all range of signals which are to be fed to a differentiating circuit by using a network of four amplifier tubes which are successively brought into operation as the signal amplitude increases and interconnected so that the output first increases, then decreases and finally increases with increasing amplitude of input.

U. S. No. 2,480,842. N. B. Farnsworth. Iss. 9/6/49. App. 3/6/45. Assign. The Sperry Corp.

Automatic Gain-Control System. An avc network for a radar scanner in which the filter has two series resistors whose junctions are grounded through a condenser and which are shunted by a condenser adjusted so as to eliminate phase shift at the output of the amplifier.

376—SEISMOMETER

U. S. No. 2,477,172. C. L. Brownlow. Iss. 7/26/49. App. 2/6/48. Assign. Phillips Petroleum Co.

Seismometer Case Cover. A cable anchoring and sealing arrangement for a seismometer, the cover having a projection with a transverse hole into one end of which the cable is held and sealed by a nut with packing and clamping inserts and the cable connections then soldered to insulated terminals accessible through the other end which is then closed by a screw plug.

U. S. No. 2,478,517. A. C. Winterhalter. Iss. 8/9/49. App. 3/25/47. Assign. Sun Oil Co.

Seismic Detector. An underwater seismic detector which is mounted in a pancake-shaped case perpendicular to the flat sides and has a gravity-operated reversing switch which maintains proper phasing.

U. S. No. 2,482,233. R. L. Arringdale. Iss. 9/20/49. App. 3/28/46. Assigns. Diamond Instrument Co.

Teleseismic Detecting, Signaling and Recording. A portable three-component seismograph having three long-period pendulums mounted on a common vertical column on a single base plate, the seismometers having eddy-current damping and electromagnetic transducers with separate amplifiers and pen recording on a single tape.

380—SEISMOMETER TESTING

U. S. No. 2,480,603. E. F. Peterson. Iss. 8/30/49. App. 6/26/46.

Machine Vibrator. A vibration generator having a rolling ball which is driven around a circular raceway in the housing by a stream of compressed air.

U. S. No. 2,481,131. J. R. Lindsay. Iss. 9/6/49. App. 11/1/41. Assign. The Jeffrey Co.

Vibrating Apparatus. A vibrating table mounted on springs and having an electromagnetic motor suspended under the table by flat springs and actuating a reaction mass.

416—SPECTROGRAPH

U. S. No. 2,480,636. G. H. Dieke. Iss. 8/30/49. App. 2/18/47.

Oscillographic Method of and System for Spectrographic Analysis. A spectrograph having photocells at the positions of principal lines, the outputs of the photocells being successively connected to deflect a c-r tube spot so that an intensity-wave length pattern is produced.

U. S. No. 2,483,244. R. F. Stamm. Iss. 9/27/49. App. 3/21/45. Assign. American Cyanamid Co.

Wernicke Prism Spectrometers and Improved Liquids Therefor. A Wernicke dispersing prism for Raman spectroscopy having similar glass end prisms and the liquid section between them filled with an ester of cinnamyl and cinnamylidene derivatives of fatty acids of the aliphatic series.

420—SPECTROPHOTOMETER

U. S. No. 2,481,034. J. Neufeld. Iss. 9/6/49. App. 9/25/44.

Apparatus for Determining Light Characteristics of Clouds by Reflection. A system for measuring the height and character of clouds by projecting a searchlight beam up to the cloud and at a known horizontal distance away measuring the elevation angle and the ratio of intensities of reflected light with two photocells filtered for different frequency bands.

428—STRAIN GAUGE

U. S. No. 2,475,614. W. H. Hoppmann, II and E. C. Taylor. Iss. 7/12/49. App. 9/21/45.

Apparatus for Electrically Measuring Strain Applied in Testing Strength of Materials. An impact tension testing machine having filament-type strain gauges on a supporting bar which is in series with the specimen.

U. S. No. 2,476,410. A W. Gardiner. Iss. 7/19/49. App. 12/21/42 and 6/24/44. Assign. General Motors Corp.

Torque Meter. A capacity-type shear strain gauge having insulating collars at spaced points on the shaft and tubes mounted on the collars concentric with the shaft with adjacent square teeth whose electrical capacity variation is measured.

U. S. No. 2,478,720. W. A. Sourwine, H. M. Maynard and A. H. Flax. Iss. 8/9/49. App. 7/20/44. Assign. Curtiss-Wright Corp.

Strain-Stress Computer. An electric network having three Wheatstone bridges each containing an element of a filament-type strain rosette for computing the axial stresses and shear stresses.

U. S. No. 2,481,371. W. D. Van Dyke. Iss. 9/6/49. App. 7/25/45. Assign. Douglas Aircraft Co., Inc.

High-Temperature Strain Gauge and Method of Making Same. A filament-type strain gauge in which the filament wire is bonded to the material to be tested by a fused vitreous cement and with the terminals heat-insulated by a ceramic tube.

U. S. No. 2,482,477. F. W. Godsey, Jr. Iss. 9/20/49. App. 8/10/44. Assign. Westinghouse Electric Corp.

Electrical Torque Measuring Device. A strain gauge for a rotating shaft without slip rings in which two annular coils about the shaft have their magnetic circuits completed through collars on the shaft carrying axially-extending fingers so that the air gap between the fingers varies with strain.

436—SUBMARINE SIGNALING

U. S. No. 2,477,246. R. W. Gillespie. Iss. 7/26/49. App. 5/16/45. Assign. Bell Telephone Laboratories, Inc.

Submarine Signaling Device. A submarine signaling hydrophone having a hollow rubber housing with piezoelectric crystal units mounted so that one end is on the housing and the other end is free.

448—TENSION INDICATOR

U. S. No. 2,477,774. E. S. Staples. Iss. 8/2/49. App. 11/29/46.

Load Range Multiplier for Use with Dynamometers. A device for increasing the range of a dynamometer by inserting it in one arm of a chain and bar force triangle.

452—THERMAL LOGGING

U. S. No. 2,480,720. H. J. Eastman. Iss. 8/30/49. App. 5/8/44. Assign. Eastman Oil Well Survey Co.

Method of Locating Water and Gaseous Fluid Stratas in Well Bores. A method of locating the point of entry of water and gas by running a temperature log of the well, bailing to reduce the hydrostatic pressure and running successive temperature logs to detect points of temperature change.

456—THERMAL PROSPECTING

U. S. No. 2,475,138. C. B. Hood, Jr., W. Jones and H. L. Johnston. Iss. 7/5/49. App. 10/31/44. Assign. U. S. A.

Device for Measuring Thermal Conductivity. A device for measuring thermal conductivity of spherical samples of material by electrically supplying heat at the center of the sphere and observing the surface temperature at steady state with the sphere suspended in an evacuated chamber in a constant-temperature bath.

460—THERMOMETER

U. S. No. 2,477,819. G. K. Newell. Iss. 8/2/49. App. 3/30/44. Assign. The Westinghouse Air Brake Co.

Temperature Responsive Apparatus. A thermometer for a hot-box alarm system having two resistance elements of different temperature coefficients which are connected to opposing solenoids of an indicator.

U. S. No. 2,477,835. L. E. Smith. Iss. 8/2/49. App. 10/19/44. Assign. The Bristol Co.

Thermometric Apparatus. A liquid-filled variable-volume thermometer in which increased speed of response is attained by having a small quick-acting element connected in opposition to the normal element.

U. S. No. 2,482,897–900. P. G. Chace. Iss. 9/27/49. App. 6/23/41 and 11/11/44. Assign. Metals & Controls Corp.

Corrosion-Resisting Composite Metal. A bimetallic thermostatic material made of an alloy of iron fused to an alloy of copper.

464—THERMOSTAT CONTROL

U. S. No. 2,480,470. C. C. Hulbert. Iss. 8/30/49. App. 6/1/46. Assign. The Pure Oil Co.

Thermostatically Controlled Bath. An electrically-heated constant-temperature bath in which part of the auxiliary heater is a lamp whose radiation falls on the thermostatic element with the distance between lamp and element adjustable.

468—TIME INTERVAL METER

U. S. No. 2,482,184. H. W. Hoffman and G. H. Helmer. Iss. 9/20/49. App. 5/26/45. Assign. Federal Cartridge Corp.

Chronographic Apparatus and Method. A projectile chronograph in which the projectile interrupts light beams to photocells whose outputs are magnetically recorded on a constant speed disk.

472—TIMEPIECE TESTING

U. S. No. 2,479,875. F. W. Meredith. Iss. 8/23/49. App. 6/30/43 and 2/21/44. Assign. S. Smith & Sons (England) Ltd.

Apparatus for Comparing the Natural Frequency of a Mechanical Oscillatory System with a Standard Frequency. A testing table which is oscillated at a standard frequency and the phase of forced oscillations of a timepiece balance wheel compared with the driving oscillations.

484—TRANSDUCER

U. S. No. 2,474,993. G. C. Tibbetts. Iss. 7/5/49. App. 11/29/45. Assign. Tibbetts Laboratories.

Phonographic Transducer Device. A phonograph pickup in which the stylus is mounted on a flat bar which is twisted by lateral motion of the stylus but which resists vertical motion and with a transducer connected to the bar.

U. S. No. 2,475,148. F. Massa. Iss. 7/5/49. App. 4/16/45.

Transducer Means. An electromechanical transducing element having a bimetallic strip one member of which has a positive magnetostrictive effect and the other member a negative magnetostrictive effect, the strip being magnetized longitudinally by a permanent magnet and wound with a pickup coil so as to be sensitive to vibratory bending of the strip.

U. S. No. 2,476,414. W. H. Hutter. Iss. 7/19/49. App. 5/24/45.

Phonograph Pickup Having Plastic Torsion Arm. A crystal-type phonograph pickup in which the stylus is directly connected to the crystal by means of an organic plastic material such as nylon.

U. S. No. 2,476,684. W. K. Rieber. Iss. 7/19/49. App. 10/12/45.

Phonographic Transducer. A variable reluctance magnetic-type phonograph record cutter or pickup in which the elastic suspension element is a stretched ligament whose tension may be changed to adjust the stiffness of the system in changing from recording to playback.

U. S. No. 2,476,685. W. K. Rieber. Iss. 7/19/49. App. 1/26/46.

Dual Purpose Transducer with Recording Damping Means. An electromagnetic-type phonograph record cutter or pickup in which the stylus pressure may be changed by a hinged weight which is allowed to ride on the recording head for recording and is lifted off during playback.

U. S. No. 2,476,778. R. Smoluchowski. Iss. 7/19/49. App. 6/28/46. Assign. General Electric Co.

Magnetostrictive Device. A magnetostrictive core construction using a series of concentric differentially-acting tubes which are alternately of positive and negative magnetostrictive material.

U. S. No. 2,477,246. R. W. Gillespie. Iss. 7/26/49. App. 5/16/45. Assign. Bell Telephone Laboratories, Inc.

Submarine Signaling Device. A submarine signaling hydrophone having a hollow rubber housing with piezoelectric crystal units mounted so that one end is on the housing and the other end is free.

U. S. No. 2,477,596. C. K. Gravley. Iss. 8/2/49. App. 8/29/47. Assign. The Brush Development Co

Electromechanical Transducer Device. A crystal speaker in which an expanding crystal is cemented to a base with a thin layer of rubber which is relatively stiff for compression and has high shear compliance so as to decouple undesirable modes of vibration.

U. S. No. 2,478,223. G. A. Argabrite. Iss. 8/9/49. App. 3/1/46. Assign. Clarkstan Corp.

Electrostrictive Translator. A piezoelectric crystal unit whose resonance is adjusted by attaching to its surface a metal backing which increases the stiffness or the mass.

U. S. No. 2,478,642. J. J. Root. Iss. 8/9/49. App. 10/9/46.

Combined Moving Coil Loudspeaker and Transformer. A dynamic speaker having its voice coil on a large-diameter form at the periphery of the cone with a ring-shaped permanent magnet provided with annular pole pieces and an annular transformer in a recess in the magnet structure.

U. S. No. 2,478,712. R. J. Rockwell. Iss. 8/9/49. App. 4/3/47. Assign. Crosley Broadcasting Corp.

Electrodynamic Phonograph Pickup. A phonograph pickup in which the stylus vibrates a single loop in a permanent magnet field, the loop being formed of light weight lap-seamed tubing with a damping material in the seam.

U. S. No. 2,479,072. R. Lee. Iss. 8/16/49. App. 11/30/42.

Electrical Apparatus. A transducer having two closely-spaced pancake coils, one being movable and one stationary, and connected in series opposition and tuned with a condenser which is adjusted slightly off resonance to an exciting oscillator.

U. S. No. 2,479,894. E. F. Andrews. Iss. 8/23/49. App. 2/11/42. Assign. N. Marshall Seeburg.

Pickup with Two Needles. A phonograph pickup having two oppositely-directed needles both mounted on a torsion wire connected to a piezoelectric crystal.

U. S. No. 2,479,926. C. K. Gravley. Iss. 8/23/49. App. 10/11/47. Assign. The Brush Development Co.

Electrotransducer and Method of Making Same. A piezoelectric transducer on which sharp edges are avoided by fusing the wire leads through the crystal to make contact with the electrodes.

U. S. No. 2,479,987. A. L. W. Williams. Iss. 8/23/49. App. 10/11/47. Assign. The Brush Development Co.

Multiplate Electrotransducer. A piezoelectric bending unit made by placing a loop of wire between two crystals and electrically heating the wire to fuse the crystals at their ends.

U. S. No. 2,480,272. E. O. Thompson. Iss. 8/30/49. App. 1/20/44. Assign. Philco Corp.

Phonograph Pickup Device. A pickup for lateral-cut records in which the stylus is held on an elastic eccentric arm connected to a small mass so that the system has a resonance point at the upper limit of the recording range.

U. S. No. 2,480,535. F. J. Alois and R. W. Samsel. Iss. 8/30/49. App. 3/13/47. Assign. General Electric Co.

Enclosure for Vibratile Elements. A piezoelectric hydrophone in which all but the active faces of the crystals are covered with a soft material and the entire unit sealed in a mass of sound transparent plastic.

U. S. No. 2,480,907. R. Dally. Iss. 9/6/49. App. 6/20/45. Assign. Electrovox Co., Inc.

Phonograph Pickup. A phonograph pickup in which the stylus produces torsional vibrations of the needle chuck which is elastically supported in a tubular shaft connected to a crystal element.

U. S. No. 2,481,068. F. P. Best. Iss. 9/6/49. App. 11/27/44 and 11/27/45. Assign. Marconi Sounding Device Co. Ltd.

Electroacoustic Translator, Including Impedance Matching. A system for coupling a submarine-signaling transducer to sea water by interposing a liquid of high acoustic resistance such as mercury between the transducer and the ships' hull.

U. S. No. 2,482,081. W. H. Unger. Iss. 9/13/49. App. 12/19/44.

Electrostatic Pickup. A phonograph pickup in which the stylus carries a metal condenser plate on a small cantilever beam of plastic and having an adjacent stationary condenser plate whose distance may be adjusted.

U. S. No. 2,482,467. R. F. Corbett. Iss. 9/20/49. App. 5/10/46. Assign. Westinghouse Electric Corp.

Phonograph Pickup. A phonograph pickup in which the stylus is mechanically connected on each side to loops of strain-sensitive wire, the wire loops being in circuit with a battery and push-pull transformer.

U. S. No. 2,482,972. J. F. Gordon. Iss. 9/27/49. App. 9/10/45. Assign. Bendix Aviation Corp.

Electron Tube Type Phonograph Reproducer. A phonograph pickup having a triode vacuum tube with a control grid mounted on a diaphragm in the envelope and the stylus connected to the grid through the diaphragm.

U. S. No. 2,483,196. J. F. Gordon. Iss. 9/27/49. App. 4/11/47. Assign. Bendix Aviation Corp.

Phono-Pickup. A magnetic phonograph pickup having a horseshoe magnet with elastic extensions which are moved in and out of alignment by a stylus mounted on a rubber block between the extensions.

U. S. No. 2,483,317. C. Laurent. Iss. 9/27/49. App. 1/27/44 and 1/7/46.

Carbon Type Microphone. A carbon granule microphone whose stationary electrode has a concave depression in the center surrounded by a plane portion and whose movable electrode has a convex portion in the center and a larger plane portion so as to form an annular granule chamber around the stationary electrode.

500—VOLTMETER

U. S. No. 2,475,827. H. M. Evjen. Iss. 7/12/49. App. 11/6/45. Assign. Nordel Corp.

Electrical Measuring System. A system for detecting balance when low-frequency a-c voltages are compared in opposition, the unbalance being amplified and applied to the control grid of a critically-biased relaxation oscillator.

508—WATER LOCATING (in wells)

U. S. No. 2,480,490. C. Mark, Jr. Iss. 8/30/49. App. 4/11/45. Assign. Clayton Mark & Co.

Electric Water Depth Gauge. A device for locating the water level in a well by lowering an insulated cable with an electrode of a metal which sets up a galvanic cell when immersed in water and with electrode and ground connected to a galvanometer.

516—WELL SIGNALING

U. S. No. 2,479,518. S. A. Scherbatskoy. Iss. 8/16/49. App. 3/9/45. Assign. Well Surveys, Inc.

Recording Apparatus for Correlating Measurements in Accordance with Depth. A system of continuous well logging in which the logging record is put on a clock-driven magnetic tape in the well device, and the depth is recorded as a function of time on a clock-driven magnetic tape at the surface by recording the output of an a-c generator driven from the hoisting cable, and the latter record used to control the chart drive of a record-translating apparatus.

520—WELL SURVEYING

U. S. No. 2,476,136. H. G. Doll. Iss. 7/12/49. App. 4/27/39 and 4/19/40. Assign. Schlumberger Well Surveying Corp.

Method and Apparatus for Locating Predetermined Levels in Bore Holes. A method of locating levels in a well by shooting into a known formation a marker which can later be located through the casing.

U. S. No. 2,476,137. H. G. Doll. Iss. 7/12/49. App. 5/16/42. Assign. Schlumberger Well Surveying Corp.

Method of Positioning Apparatus in Boreholes. A method of locating levels in a well by placing in a known formation a marker which can be located through the casing, then placing a mark in the casing at a known location with respect to the formation marker and later positioning apparatus with respect to the casing marker.

REVIEWS

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C. G. DAHM, Magnolia Pet. Co., Dallas.

The Location of Underground Water by Geological and Geophysical Methods. Compiled from technical work of the unit by the 42nd Geological Section S.A.E.C., U.D.F., M.E.F. published by G.H.Q., M.E.F. April 1943. 96 pages including 28 pages of diagrams, curves, and sketches.

This pamphlet, a copy of which was given to me by an officer of the Royal Engineers after a "bull-session" in Bengazi, appears to be an excellent outline to guide officers and men who might be charged with the responsibility of adequate water supply for an army operating in desert areas. It is written in such form as to be useful to the layman, yet contains enough detail to be interesting to the professional engineer and geologist.

Chapter I covers the "Geology of Underground Water Supplies" and is subdivided into such headings as—(1) Controlling factors; which include rainfall, topography, rock texture, structure, etc. (2) Rocks of sedimentary origin: various types of sediments and alluvial gravels to shales and clays are briefly discussed with reference to porosity, permeability and water retaining character. (3) Rocks of igneous origin: this section is sub-divided into plutonic, extrusive, intrusive, etc. rocks, with discussions of each. (4) Metamorphic rocks are similarly treated. (5) Special structures: under this heading the various structures that may affect water supplies are discussed, e.g. faults, which may provide an outlet for artesian supplies or conversely, permit water to penetrate to depths beyond reach; other artesian or subartesian conditions, etc. Numerous diagrams are included showing proper location of wells for various types of structure, surface and sub-surface soil and rock types; examples of artesian flow, perched water fables, etc.

The remaining two thirds of the pamphlet is devoted to the use of electrical and magnetic methods of prospecting for structures or conditions favorable to water supply. Chapter II gives a brief outline of the essential theory and description of instruments, such as the milliammeter-potentiometer apparatus and the megger earth tester, used in electrical methods of prospecting. Chapter III covers briefly the interpretation of resistivity curves, citing examples of various conditions to be expected such as soil, clay, gravel, limestone, and other surface desposits and the effect of each. Numerous examples of actual surveys are given covering various localities in the Middle East. A short discussion of borehole logs and their correlation with the interpretations of electrical surveys is included. Chapter IV outlines the organization and operation of field parties. Actual surveys in the various types of terrain found in the Middle East are cited as examples.

Chapter V briefly outlines the principles of the magnetometer, its construction, use, and the interpretation of observed data. Field procedure is outlined very briefly.

An appendix to this pamphlet includes tables of resistivity constants, porosities, and magnetic susceptibilities of various types of soil and rock.

The bibliography includes some of the better works of American, English, and European authors.

RICHARD H. HOPKINS

"A New High Sensitivity Remanent Magnetometer" by E. A. Johnson, T. Murphy, and P. F. Nichelsen. *Rev. Sci. Instr.*, June, 1949, p. 429.

In sedimentary geological materials magnetic particles are subjected to orienting forces by the earth's field during the period of deposition. When solidified, the magnetization of such materials is

considered to be indicative of the field at that time. The apparatus described in this paper has been used to measure the magnetizations of samples of ancient clays and sediments and of 150 million year old rocks in order to learn more about the early character of the earth's magnetism. Aside from geological aspects the equipment has also been used in a study of the character of magnetic domains. The procedure consists of rotating a sample near a coil and measuring the induced voltage. The voltmeter is calibrated in units of magnetic moment. For the comparison of samples, moment readings are reduced to unit volume of sample. The phase of the voltage is also observed from which the direction of magnetization of the sample is determined.

The voltage is measured by means of an AC amplifier, rectifier, and DC meter. Voltage readings are converted to magnetic moments from 10^{-6} to 20 c.g.s. units by the use of a calibrating magnet. About 2×10^{-6} is considered the practical limit of measurement. The phase is measured by means of an electronic wattmeter. This requires a reference voltage which is obtained from a coil and separate magnet attached to a rotating shaft. The reference voltage is fed to a modulator circuit along with the voltage from the sample. The phase of the reference voltage is adjusted until a null indication is obtained by shifting the coil on its support. From the amount of shift required the direction of magnetization of the sample is obtained. The wattmeter is phase selective and has greater sensitivity than the voltmeter. Moments as small as 5×10^{-7} c.g.s. units can be detected. This corresponds to a voltage of 8×10^{-11} volts in the pick-up coil. A gain of 275 is obtained in the input transformer. A high level of tube amplification is available. Compensation is provided for induction pick-up from the motor by means of a separate rotating magnet and pick-up coil. Part of the voltage generated in this coil is fed to a bucking coil placed parallel to the sample pick-up coil.

The equipment is portable for field use, sturdy, and has extremely high sensitivity. The description is given in considerable detail, illustrated with sketches and a complete circuit diagram. It should be possible to duplicate the equipment readily.

ALEX FROSCH

"Auswertung geophysikalischer Sondierungen mit Hilfe von Potentialfeldern" ("Evaluation of Geophysical Surveys Making Use of Potential Fields") by F. Gassmann. *Schweiz. Min. Petr. Mitteilungen*, Bd. XXVII, Heft I (1948).

The purpose of Prof. Gassmann's paper is to show the essential unity of all geophysical prospecting methods which make use of potential fields. Such fields are encountered in gravity, magnetic, and electrical prospecting as well as in electrical and thermal well logging. The author endeavors to generalize the interpretation procedures used in potential field techniques and to set up a mathematical formulation which covers them all. The mathematical reasoning may be summarized in words as follows:

Any methods of geophysical exploration which are based on steady state conditions describable by potential theory (as opposed to dynamic methods based on wave propagation theory) make use of field vectors derivable from the negative gradient of the potential. For such methods the potential of any complicated system of sources is reducible to the integration of a combination of elementary sources, namely, point, line, dipole and dipole line. The secondary field arising from the action of a primary field is expressible as a tensor of the primary field as long as the secondary components are linear functions of the primary field components. Parallel expressions are listed for the quantities arising in hydrodynamics, direct current and heat flow, gravity, electrostatics and magnetostatics.

Interpretation consists in determining the sub-surface source distribution from surface measurements of the potential or field. It is emphasized that the application of potential theory alone leads to manifold possible solutions which can be narrowed down by application of known geologic controls to a relatively certain solution.

Approximating the observed potential field by a subsurface source distribution should take place in two steps, a preliminary evaluation and then a more accurate approximation or fit. The more accurate approximation is achieved by setting it up as a Taylor series. The preliminary evaluation is

the first term, while the additional terms contain the derivatives of this preliminary evaluation with respect to the successive parameters defining the source distribution. Each derivative is multiplied by the variation in each parameter necessary to bring the more accurate approximation to fit the observed values. If only the first order differentials are considered and these replaced by appropriate difference coefficients, then a series of n practically useful equations can be set up. These involve the variations of the n parameters necessary for an accurate fit of the field data, and the differences between the observed and preliminary evaluations for n selected points. From such equations the required variations in the n parameters from their preliminary values can be determined.

A. A. BRANT

"Gravimetermessungen über der jungen Vulkanzone Islands" ("Gravity Measurements over the Young Volcanic Zone of Iceland) by Dr. A. Schleusener, Hannover. From *Spalten auf Island*, O. Niemczyk, Konradwittwer, Stuttgart, 1943.

This paper discussed the gravity work of the German combined geophysical, geodetic, and geological expedition to Iceland in 1938. The work was carried out with the Thyssen gravimeter, which is described in detail together with its operating characteristics. Forty stations were occupied, the data being tied to pendulum measurements simultaneously taken by the expedition. The Bouguer ($\Delta g_0''$) and regional free air anomalies ($\Delta g_0'm$) were computed and used. Local free-air anomalies (Δg_0) were found too dependent on elevation to be useful.

Referring back to pendulum measurements taken some 40 years ago over the seismically active Eya fjord, it was found that the gravity difference between stations at Akueyri and Glaesibaer deviated by 16 milligals from the old measurements. However, the deviation appears to be due not to a secular variation but to errors of measurement in the older work.

At the Bardartal Fault where the young palagonite tuff abuts against old basalt, there was an excess of gravity of about 8 milligals over the down-dropped block of the tuff, in place of an expected deficiency of 10–20 milligals. The abnormal gravity conditions could be explained through the assumption of an underlying layer of old palagonite tuff (density 2.30) beneath the basalt (density 2.77). On the down side of the fault a thicker section of basalt could be present, though covered by a young layer of palagonite tuff; while on the up thrown side the basalt, having been eroded so that its total thickness is less, could be covered by glacial drift. This is merely one interpretation.

The entire region falls into a series of gravity zones trending north and south. These appear as highs and lows over both the old basalt and the young volcanic zones. The individual geologic units are 15–20 km. across and partially coincide with the over-all gravity zones.

If there is isostatic compensation corresponding to a mean elevation of 300 meters, one would expect free air anomalies ($\Delta g_0'm$) of about ± 0 milligals but instead they actually average $+60$ milligals. If similar gravity conditions exist over the whole island, one must conclude that Iceland is not in isostatic equilibrium. Yet this excess gravity is too small to indicate the presence of such heavy masses at depth as are suggested for volcanic islands such as Oahu with their much larger free air anomalies.

A plot of the free air anomalies in general follows the average elevation. Thus, the individual geologic units are apparently not in equilibrium from an isostatic point of view.

Bernauer has proposed that an uplift was caused in the young volcanic zone by a double cyclical convection current, but the gravity data do not fit all the premises of position, depth, lateral extent and phase required by this hypothesis. They would fit better if a deficiency rather than an excess in gravity had been observed over the Bardatal graben. It may be however that some other kind of convection stream does enter into the situation. It is concluded that not much help can be expected from other geophysical methods in the solution of this problem.

C. G. DAHM

"The Disturbance Due to a Line Source in a Semi-Infinite Elastic Medium" E. R. Lapwood, *Phil. Trans. Roy. Soc. Lon.*, Ser. A, no. 841, vol. 242 (1949), pp. 63–100.

The solution of the problem of radiation of elastic waves from line and point sources located in a semi-infinite elastic solid was given by Lamb in a classical paper published in 1904. If the curvature of P or SV waves incident and reflected at the free surface is taken into account, the condition of zero stress at the surface can only be satisfied if a system of Rayleigh waves is included in the solution. Thus Lamb found that the surface displacements at a distant point from an impulsive line or point source in the medium consists of waves arriving in the following order: P-pulse, S-pulse, Rayleigh pulse.

Lamb's method consisted of obtaining the formal solutions for a periodic line or point source as definite integrals which are then evaluated in terms of branch line integrals and residues in the complex plane. The solutions for simple harmonic vibrations at the source are subsequently generalized for the case of an arbitrary initial disturbance. This approach was subsequently utilized by Sezawa, Pekeris and others to study the normal mode solutions for elastic waves in layered media.

Nakano (1925) extended Lamb's solution for a line source located below the surface, evaluating the integral expressions by the method of steepest descents. His solution yielded additional information on the surface displacements near the source and on the surface displacements arriving prior to the Rayleigh wave.

Lapwood's investigation was prompted by several unusual features of Nakano's results. Nakano concluded that the surface displacements at a distant point due to an initial P vibration consist of the direct P-wave, the Rayleigh wave, and a surface S-wave which is unexpected if one thinks in terms of the ordinary geometrical theory. Nakano obtained for an initial S vibration, the direct S-wave, the Rayleigh wave and a surface P-wave which agrees with geometric theory. When he generalized his results for an arbitrary initial disturbance, Nakano did not find surface S-waves, making their existence uncertain.

Lapwood obtains formal solutions for an initial disturbance of the form of the Heaviside unit function, following Jeffreys' suggestion that a unit function is more representative of the initial conditions at the focus of an earthquake. The formal solutions, expressed as integrals, are evaluated along contours first introduced by Sommerfeld, giving a more convenient and complete analysis than that of Lamb or Nakano.

Lapwood establishes the reality of the two surface pulses suggested by Nakano. He shows that the surface P-pulse is not a true surface wave but is more like the doubly reflected body wave sPs. The surface S-wave PS_p however is a true surface wave in that it is confined to the vicinity of the surface, but unlike the Rayleigh wave it does not exist as a free vibration.

In a concluding section Lapwood suggests that the observed scatter in the times of S of near earthquakes may be due to the existence of the surface S-wave and the spreading of the direct S-wave indicated by the theory.

FRANK PRESS

"Magnetic Polarization of Sedimentary Rocks and the Earth's Magnetic History" by O. W. Torreson, Thomas Murphy, and John W. Graham. *Journal of Geophysical Research*, vol. 54, pp. 111–129 (1949).

"The Stability and Significance of Magnetism in Sedimentary Rocks" by John W. Graham. *Journal of Geophysical Research*, 54, pp. 131–167 (1949).

About a decade ago Herrick and Lynton proposed a method of orienting core samples by determining the direction of the core's magnetic polarization. The original attitude of the core would then be ascertained by comparing the direction so measured with that of the earth's magnetic field. Some question was raised at the time as to the safety of assuming that all sedimentary formations in the earth are now polarized in the same direction as the present earth's field. The objections were

based on some measurements made during 1937 and 1938 by the Department of Terrestrial Magnetism on the magnetic polarization of varved glacial clays laid down 20,000 years ago in Connecticut. Deposited over a time interval of 500 years, these showed a wide difference between the horizontal component of the polarization in the clays and the present declination in the area.

In 1946 and 1947 this work was resumed with an improved magnetometer and the clay samples were chosen from layers with times of deposition known to cover a 5,000-year interval. Flat-lying beds were found to have highly consistent polarization directions while folded sections gave very scattered polarizations. From this it was concluded that the earth's field had had little effect on the polarizaton in the 15,000 to 20,000 years since the folding had taken place.

The work described in the two current papers represents extensions of the measurements on the New England varved clays to other areas and other lithologies as well as to much more ancient periods of geologic history. The first paper describes an expedition sponsored by the D.T.M. to study magnetic polarizations at a number of representative localities in the western United States. Using a pair of trucks (one containing equipment, the other providing living facilities), the investigators traveled 7,750 miles to obtain measurements at twelve working sites in areas extending from the South Dakota Badlands to Yakima, Washington.

The experimental procedure was 1) to mark the direction on a sample *in situ*, 2) to remove the sample by chisel and crowbar, 3) to prepare a properly sized sample for measurement by coring bit (in the case of hard rock) or by sawing or hand shaping (in the case of soft rock or clays), and 4) to measure the polarization intensity and direction by rotating the sample about two non-parallel axes in a special high-sensitivity inductor type magnetometer. A review of an article describing the instrument is presented in another part of the reviews section. Both inclination and declination were measured.

The first paper discusses only the samples taken from flat-lying beds. These varied in age from Jurassic to Pliocene (125–150 million years to 5–10 million years). There was some scatter in the data but distribution curves of declination and inclination (number of observations indicating a value within a given range of D or I angles vs. the average angle) showed very sharp and well defined peaks for both elements. The average declination angle in the samples was found to be zero degrees with the geographic north as opposed to an average declination of about 17° in the present earth's field. The average inclination of all samples was found to be 63°, as compared with an average present value of 69° in the areas investigated. The conclusion is suggested, although not of course confirmed with so limited a number and range of samples, that the earth's field has tended to point in the direction of its axis of rotation for at least 50 million years with little evidence of deviations essentially greater than that observed at present.

Graham's paper is concerned with the effect of folding and other deformation upon the direction of magnetization in sedimentary rock. If the direction appears to have no relation to the dip or strike of the deformed stratum at the point where the sample is taken it would appear that the magnetization has been influenced by conditions existing since the deformation took place. If, on the other hand, the magnetization direction when "restored" by mathematical rotation of the bed from its present distorted to its original horizontal position turns out to be the same for samples taken from many different parts of the fold, a high stability is indicated for the original magnetization.

Graham rotated his observed polarization directions in a number of highly folded formations such as Pleistocene varved clays, Miocene river conglomerates, coarse Eocene sandstone and the Rose Hill marine formation of Maryland. For the fine grained materials such as the varved clays and the Rose Hill formation, the restored directions of polarization were remarkably consistent, indicating uniformity of magnetization upon deposition. For the coarse sandstone and conglomerate, the directions were random both before and after restoration, indicating random magnetization at the time of deposition. It thus appears that fine grained particles deposited in quiet water will orient themselves in the direction of the earth's field at deposition and maintain that original orientation despite subsequent changes in the earth's field. Large grains, such as coarse sands and pebbles or particles deposited from turbulent water will be prevented by larger contrary forces from orienting themselves with the earth's field.

It thus appears that core orientation by magnetic means is feasible only if the direction of the earth's field at the time of the sample's deposition is known. Since the earth's field appears to change its direction quite markedly in a few thousand years it is unlikely that pre-Pleistocene formations encountered in drilling could ever be dated closely enough for this method to allow precise orientation. It is only if an uncertainty as great as 40° is allowable that magnetic orientation could give usable results.

MILTON B. DOBRIN

"Subsurface Geologic Methods" edited by L. W. LeRoy and H. M. Crain. *Quarterly of the Colorado School of Mines*, vol 44, no. 3, July 1949, 826 pages.

Although subsurface techniques have taken on a steadily increasing importance in exploration for petroleum and minerals during the past quarter century, it is only with this publication that a comprehensive summary of all such methods of prospecting has been made available in a single book. The geophysicist may be surprised upon opening this volume to discover that only 303 of its 826 pages are devoted to well logging and the conventional geophysical prospecting methods. The remainder of the book deals with a multiplicity of other topics which fall more within the province of the geologist than of the geophysicist.

The variety of subjects covered can best be indicated by listing the twelve chapter headings: I. Introduction, 25 pp.; II. Stratigraphic, Structural, and Correlation Considerations, 32 pp.; III. Subsurface Laboratory Methods, 239 pp.; IV. Subsurface Logging Methods, 136 pp.; V. Miscellaneous Subsurface Methods, 162 pp.; VI. Subsurface Graphic Representations, 12 pp.; VII. Subsurface Maps and Illustrations, 32 pp.; VIII. Report on Subsurface Geology, 55 pp.; IX. Subsurface Methods as Applied in Geophysics, 75 pp.; X. Subsurface Methods as Applied in Mining Geology, 20 pp.; XI. Geologic Techniques in Civil Engineering, 30 pp.; XII. Sources of Subsurface Information, 6 pp.

Most of these topics are self-explanatory, although it might be instructive to enumerate some of the subheadings. Among the subsurface laboratory methods are micropaleontologic, thin section, petrofabric, screen, settling, stain, shape, electron-microscopic, X-ray, core, and multiple-differential-thermal analysis. The logging methods discussed include lithologic, electric, induction, radioactivity, caliper, temperature, spectrochemical sample, drilling-time, fluoroanalysis, and composite-cuttings analysis logging. The miscellaneous subsurface methods are controlled directional drilling, oil-well surveying, magnetic core orientation, oriented cores, dipmeter surveys, coring techniques, deep well cameras, and the electric pilot. Each topic is covered by a different author—forty-one have contributed to the book—and there is necessarily a wide divergence in the completeness with which various subjects are covered. The principles of resistivity logging, for example, are covered in only four pages, while drilling-time logging, surely a less important method, is treated in 26 pages.

The section that will probably be of greatest interest to readers of *Geophysics* is chapter IX, written by Harrison E. Stommel. The author has made a noble effort to cover the entire subject of geophysicsl prospecting in 75 pages, but the subject is much too diversified to permit adequate treatment in such a limited space. For the reader well versed in the fundamentals of the various geophysical methods, the numerous examples taken from the literature should be instructive. A large majority of the 43 illustrations are maps and profiles from published case histories and other results of actual surveys. For a reader unfamiliar with the fundamental principles the sketchy explanations will probably be quite insufficient to make the remainder useful.

It is inevitable that so brief an account of so extensive a subject as geophysics should have many serious omissions. In a relative valuation of the torsion balance and gravimeter the author neglects to mention one of the most serious relative shortcomings of the former instrument—its inordinate sensitivity to terrain irregularities. He makes the statement that "deflection of the vertical" is of no geological value because of insufficient precision, not mentioning the great geological importance of Hayford's pendulum data on deflection of the vertical which first established the existence of isostasy in North America. It is also stated that the future of geophysics looks "exceedingly bright" in the mining industry, without reference to the general dissent from that opinion on the part of the

experts contributing to the mining geophysics symposium at the 1948 Denver meeting of the S.E.G. The coverage of recent literature on geophysics is good and the chapter goes far toward enabling one to bring the bibliographies in the three 1940 geophysics textbooks up to date.

The chapter on civil engineering techniques presents a large number of geophysical applications in a series of charts. Some of those, such as the mapping of sub-drift topography by a gravimeter, do not look practical to the reviewer.

MILTON B. DOBRIN

South Australia Dept. of Mines, *Mining Review*, no. 87 (for second half of 1946), Adelaide (1949).

The only item in this publication likely to be of interest to the geophysicist is a four-page account of some gravity surveys carried on in the Copley-Lyndhurst area of Central Australia with the object of finding structures favorable for the accumulation of coal. The coal discovered thus far in the Leigh Creek area is of Triassic age and occurs in basins in the Pre-Cambrian rock. Since there is an unconformable cover of younger beds additional basins cannot be located by surface geology and thus they must be uncovered either by drilling or by geophysical means. Although a number of geophysical methods were tried, gravity techniques appeared to give the most promising results because of the substantial density contrast between the Triassic basin sediments and the much heavier pre-Cambrian rocks which underlie them. Since two known coal bearing basins gave gravity lows of 9 milligals and 2 milligals respectively, a low of 5 milligals in a nearby but previously unexplored area led to a recommendation for drilling. It is hoped that the next issue of this publication will let us know how successful this prospecting method turned out to be.

MILTON B. DOBRIN

"Importance des phénomènes d'anisotropie dans le problème de l'interprétation des données d'un sondage électrique," ("Importance of the phenomenon of anistropy in the problem of interpreting the results of an electrical survey") by L. Cagniard. Ann. de l'Institut de Physique du Globe, Vol. IV, No. 3 (1948), pp. 3–28.

This article brings out the importance of formation anisotropy and of the refraction of current lines in surface electrical prospecting by the resistivity method. It is shown that the determination of the distribution of the electrical resistivity in layered formations, even when not convergent, is a problem essentially indeterminate. This indeterminacy results from the fact that we do not know the degree of anisotropy of the layers. Supposing that the layers are anisotropic, it is still impossible to resolve the uncertainty, contrary to what was shown by Slichter in 1933.*

The authors shows in addition that it is always possible to fit a layered anisotropic earth to any results of surface resistivity measurement. However, this should prove to be valuable even though a systematic error is introduced, because the effect of anisotropy can be evaluated afterwards.

SILVAIN J. PIRSON

"On the Establishment of the Values of Gravity for the National Reference Stations," by R. A Hirvonen, Publications of the Isostatic Institute of the International Association of Geodesy. No. 19. Reprinted from the Annales Academiae Scientiarum Fennicae Ser. A. III, Geologica-Geographica, 17. Helsinki (1948) (In English).

This twenty-page paper considers the present status of international basic gravity stations and their adjustment to provide a single consistent net of gravity values throughout the whole world. The problem is of importance to geodesists especially in calculating the undulations of the geoid by

* L. B. Slichter, "The Interpretation of the Resistivity Prospecting Method for Horizontal Structures." *Physics* IV, pp. 307–322.

Stokes' formula. The author concludes that the present net of observations is not yet satisfactory for the establishment of standard gravity values.

The general problem and uncertainties in assigning weights to the various gravity data and the adjustment method used by the author are reported in considerable detail. It is found that internal inconsistencies in the data greatly exceed the precisions claimed by the various observers. The author states that what we need now are more observations and not accurate, elaborate adjustments. The international gravity ties executed by Woollard* during 1948 should greatly accelerate this program.

An extensive catalog of principal gravity reference stations throughout the world is included. The data given for each station are: Name, Latitude, Longitude, Elevation, and Gravity Values according to adjustments by Hirvonen, Morelli, and Borras.

SIGMUND HAMMER

* G. P. Woollard, Oral Report to Society of Exploration Geophysicists, St. Louis, Missouri, March 14–17, 1949.

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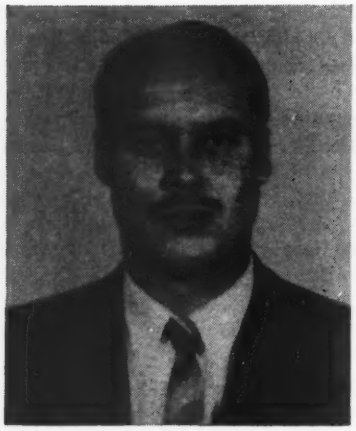
CONTRIBUTORS



JOHN BEMROSE

JOHN BEMROSE received the degree of Bachelor of Science in Pure and Applied Mathematics and Physics from the London University in 1935. After a period with the International Geophysical Prospecting Company in London where he was engaged in gravity surveys in England and Iran, he joined the Dutch Shell group of companies as a geophysicist, and worked on foreign assignments in Holland, South America, The Netherlands East Indies and The Bahamas.

His experiences have included all phases of the gravimetric, seismic and aeromagnetic methods and their interpretation.

In 1948 he joined the Sohio Petroleum Company as a research geophysicist.

Mr. Bemrose is a member of the Society of Exploration Geophysicists.

PAUL E. DAMON received the B.S. degree in Physics from Bucknell University in 1943. He served as electronic technician and watch and deck officer with the U. S. Navy from 1943 to 1946. From 1946 to 1947 he studied mathematics and physics at Rutgers University and in the fall of 1947 transferred to the Missouri School of Mines to study geology and physics, where he completed his requirements for the M.S. degree in Physics. At the present time he is a research associate with the Institute of Science and Technology, University of Arkansas, where heis engaged in nuclear research and some of the physical aspects of chemical research.

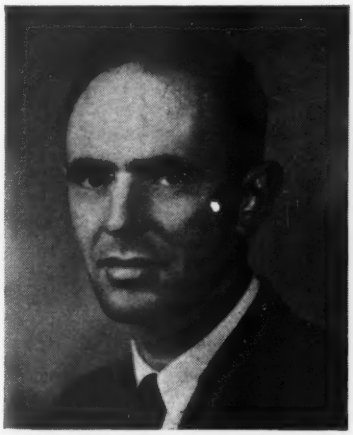
He is a member of the Society of Exploration Geophysicists, American Geophysical Union, American Association of Physics Teachers and other organizations.

PAUL E. DAMON

J. C. HEGGBLOM received his B.A. degree in Physics from the University of Wisconsin in 1929. For two years he was employed by Gulf Research and Development Company in gravity instrument work in the Pittsburgh laboratory and field work in Michigan and Oklahoma. After one year's postgraduate work at the University of Wisconsin in 1931–32, he rejoined the Gulf Research and Development Company in 1932 and has been associated with the Gulf Companies until the present time. Field work has been in gravity, magnetics and seismic operations, with service in the United States, Venezuela, Bahamas and Cuba. In 1948 he was transferred to Mozambique, Portuguese East Africa as General Manager for the Mozambique Gulf Oil Company.

He is a member of the American Association of Petroleum Geologists and the Society of Exploration Geophysicists.

J. C. HEGGBLOM



THOMAS C. HOLT

THOMAS C. HOLT studied mathematics, chemistry and physics at the University of Colorado and received a B.A. degree. Upon completing his college work, he entered the Army Air Forces. After receiving a commission at Yale University, he was assigned to the European Theater where he served in radar aerial reconnaissance with the Royal Air Force on a detached assignment from the Eighth Air Force. After being released from service, he was employed by The Superior Oil Company as a seismograph trainee. Early in 1947, he was transferred to the Bahamas Oil Company, a Superior subsidiary, as geophysicist. At present, he is with Superior in Oklahoma City doing interpretation of seismic data.

RALPH D. LYNN

RALPH D. LYNN was born in Oklahoma in 1909. He attended the University of Oklahoma hwere he received a B.A. degree in 1931 and a M.S. degree in 1933 with major in physics. He was an instructor in physics and mathematics at Cameron State Agricultural College, Lawton, Oklahoma, for the 1932–33 term. He began service with The Carter Oil Company in 1934 and was a seismograph operator when transferred to the laboratory in Tulsa in 1937. As research physicist his work has been mostly with seismic problems. From 1942 through 1946 he was on military leave during which time he served with Eighth Army Headquarters in New Guinea, the Philippines and Japan as a captain in the Artillery Section.

R. F. SIMON received his B.S. in E.E. in 1935 from the University of Texas, where he was a member of Phi Eta Sigma, Eta Kappa Nu, Tau Beta Pi, AIEE, and the students assembly.

From 1935 to 1937 he was associated with the Dallas Power and Light Company, and returned in the latter year to Texas University for a year's graduate study in Electrical Engineering.

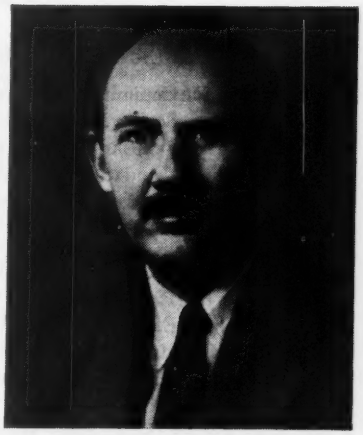
From 1938 to the present, Mr. Simon has been associated with the Magnolia Petroleum Company, first with the Geophysical Department and since 1942 with the Field Research Laboratories. With the latter group's Experimental Seismic crew he has functioned as computer, Party Chief, and Supervisor. He is a member of the Dallas Geophysical Society.

R. F. SIMON

GEORGE P. WOOLLARD was born December 20, 1908 in Savannah, Georgia. He received the B.S. degree in C.E. in 1932, and the M.S. degree in 1934 at Georgia School of Technology. He received the Ph.D. degree at Princeton University in 1937.

He holds fellowships in the National Research Council and in the Guggenheim Foundation while studying the relation of regional geologic structure and gravity and magnetic anomalies. He is also a visiting lecturer at Princeton University and Rutgers. From 1941 to 1947 Dr. Woollard was a research associate at Woods Hole Oceanographic Institution working on underwater acoustics and the effect of ocean bottom types in Anti-Submarine Warfare for the U. S. Navy.

At present he is Associate Professor in the Department of Geology of the University of Wisconsin, teaching Engineering Geology and Geophysics. He is a research associate at W. H. O. I., and current chairman of the Special Committee for Geophysical and Geological Study of Continents in the American Geophysical Union. He is a member of the Society of Exploration Geophysicists.



GEORGE P. WOOLLARD

P. HAZEBROEK

P. HAZEBROEK graduated in Mathematics and Physics at the University of Leyden (Netherlands) in 1932 and received there his Sc.D. degree with a thesis on projective differential geometry.

From 1938 Dr. Hazebroek has been employed by the N. V. De Bataafsche Petroleum Maatschappij at The Hague, where he has been engaged most of the time on theoretical geophysical research. During the war he worked for some years on the theory of automatic control.

In addition, references are cited to earlier issues for the biographies of: Norman Ricker, Vol. VI, No. 3 (July 1941); D. H. Clewell, Vol. VII, No. 2 (April 1942); G. Morris, Vol. XI, No. 3 (July 1946); R. B. Rice, Vol. XIV, No. 2 (April 1949); T. C. Richards, Vol. XI, No. 3 (July 1946) and R. J. Watson, Vol. XIV, No. 2 (April 1949).

SOCIETY ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following candidates for membership in the Society. This publication does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualification of these nominees, he should send it to the president within thirty days. (Names of references appear in parentheses after the name of each nominee.)

ACTIVE

Ralph Hardie Akin (G. E. Wagoner, H. M. Buchner, W. W. Clark)
Burt Beverly, Jr. (P. P. Gaby, C. H. Breen, O. F. Van Beveren)
Ross Henry Bird (E. W. Frowe, R. W. Griffin, J. C. Pollard)
Dorothy Mae Boardman (W. B. Robinson, P. C. Cerveny, W. C. Lamb)
Jacques Jean-Marie Bulhon (E. G. Leonardon, J. C. Legrand, R. Henquet)
Edgar Steward Driver (W. C. Lamb, D. M. Weber, W. B. Robinson)
Cleon Boyd Forbes (K. E. Burg, D. R. Dobyns, R. G. Sohlberg)
Sidney Stewart Galpin (W. B. Robinson, P. F. Cerveny, W. C. Lamb)
John Garrett Harrell (Sidon Harris, P. H. Ledyard, R. H. Dana)
Richard John Hughes, Jr. (D. W. Jopling, F. K. Fisk, E. J. Stulken)
Nils Henderson Lago (E. G. Schempf, E. E. Conant, R. R. Phillips)
Alastair Lamont (F. W. Hales—Bylaws Article III, Section 2)
Homer Windsor Lawrence (E. van der Linden, A. A. Fitch, H. M. Thralls)
James Thornton Lodge, Jr. (J. A. Gillin, W. H. Amis, E. D. Alcock)
George Edward Manger (J. H. Swartz, H. R. Joesting—Bylaws Article III, Sec. 2)
Frank Press (N. C. Steenland, R. A. Geyer, M. B. Dobrin)
Weiman Herman Reese (E. J. Shimek, W. B. Hurt, Hart Brown)
Edmund Lee Ricketts (E. S. Barclay, J. D. Marr, A. J. Hintze)
Donald West Rockwell (J. W. Thomas, J. C. Hoffman, K. E. Burg)
James Alva Treybig (R. L. Lay, C. C. Zimmerman, W. C. Kimball*)
Joseph Samuel Welboan, Jr. (L. A. Scholl, Jr., R. L. Lay, A. A. Hunzicker)
James Edward White (D. H. Clewell, G. E. White, C. W. Horton)
Jackson S. Young (C. H. Green, E. D. Gaby, H. M. Buchner)
Isidore Zietz (Henry Joesting, Irwin Roman,* J. H. Swartz)

ASSOCIATE

George Robert Belt (W. C. Lamb, R. B. Ross, F. O. Mortlock)
George Philippe Brognon (K. E. Burg—Bylaws Article III, Sec. 2)
Albert Joseph Christman (C. C. Zimmerman, H. W. McDonald, C. V. Aderman)
Ernest Ewart Cook (F. A. Van Melle, J. B. Jackson, N. H. Prade)
Robert David Darnell (F. J. Agnich, E. J. Stulken, F. J. Williams)
Donald Dean Dominy (W. B. Hurt, Hart Brown, E. J. Shimek)
Carl Fredrick Eakin, Jr. (G. M. McGuckin, D. W. Autrey, W. C. Clark)
James Coy Eley (R. M. Nugent, J. C. Menefee, P. E. Nash)
Berkley Talmadge Fleming (E. D. Gaby, George Augustat, A. G. Harvey)
Lawrence William Funkhouser (J. H. Todd, W. E. Ware, V. W. Teufel)
Benjamin Franklin Giles (K. E. Burg, E. J. Stulken, F. J. Williams)
John Wyeth Green (C. H. Green, K. E. Burg, F. J. Agnich)
Furman Alexander Grimm (M. S. Morrison, J. B. Hudson, C. H. Johnson)
Juan Carlos Gurmendi (Pedro Rey, Rodolfo Martin—Bylaws Article III, Sec. 1)

* Non-member reference.

Royal Austin Hartenberger (J. P. Hughes, W. H. Courtier, R. M. Dreyer)
George Preston Howard (G. E. Conover, P. P. Conrad, A. J. Z. Caan)
John Clyde Hughes (H. Klaus, W. L. Matjasic, N. R. Shade)
Charles F. Iglehart (R. C. Coffin, G. L. Taylor, W. W. Lamkin)
Winston Leonard Irwin (F. R. Coryn, L. A. Scholl, Jr., M. J. Millet)
Pasquale Licastro (L. O. Bacon—Bylaws Article III, Sec. 2)
Robert Thurmon Loftin, Jr. (F. J. Agnich, K. E. Burg, E. J. Stulken)
Charles M. Mayhew (A. E. McKay, O. C. Clifford, Jr., R. F. Bennett)
William David McKinley (W. B. Hurt, Hart Brown, E. J. Shimek)
Charles Lee Moore (T. O. Hall, M. R. Henderson, Fred G. Knight)
Neal Neece, Jr. (J. F. Rollins, M. C. Kelsey, E. F. McMullin)
Robert George Neill (H. C. Moore, J. P. Garner, P. E. Roberts)
Francis Alfred Petersen (J. H. Todd, C. E. McClure, D. B. Harris)
Kenneth Eugene Peterson (B. J. Sorrells, W. H. Amis, L. I. Shock)
Arthur Pollet (C. P. Harkins, C. H. Broussard, T. I. Harkins)
Alan John Richardson (Perry Byerly, Robert Dyk, Robert Plumb—Assoc. Member)
Grant M. Roberts (Dean Walling, V. E. Prestine, Dupree McGrady)
James Howard Rucker (L. G. Cowles, P. C. Kelly,* K. G. McCann)
James Cleveland Russell (L. A. Davis, J. B. Hazelrigg, W. L. Moore)
David Sydney Seabrooke (O. Weiss, H. H. Brons, E. P. van der Linden)
Grover Cleveland Shivers, Jr. (Sidon Harris, E. F. Blake, Booth Strange)
James William Sickles (Henry Salvatori, Dean Walling, Harris Cox)
Orville Aldeen Strozier, Jr. (L. J. Richards, J. K. Ziegler, E. J. Handley)
Howard Edwin Thomas (W. B. Robinson, W. C. Lamb, M. D. Butler)
Joseph Wesley Thornton (Andrew Gilmour, C. M. Ross, J. T. Gilliam)
Johannes Jacob van Bekkum (A. A. Fitch, N. Frost, I. C. J. Bourne)
Woodrow Pitkin Wilson (R. C. Dunlap, Jr., E. A. Kiesler, James Everitt)
Kunapuli Venkateswarlu (J. H. Swartz, H. R. Joesting—Bylaws Article III, Sec. 2)

TRANSFER TO ACTIVE

Kenneth Edward Andrews
Herbert G. Rim
John A. Van Auken
T. J. Thomas

TRANSFER TO ASSOCIATE

Joseph E. Barthelemy, Jr.
Robert James Gilmore
William K. Rankin

REINSTATEMENT

Walter M. Small—Active

RESIGNATION

Lawson Clary, Jr.
Charles L. Heald
W. B. Kendall
R. W. Pearce
L. W. Peay, Jr.
Louis N. Waterfall

STUDENT MEMBERS ELECTED

The following students have been elected to student membership in the Society in accordance with Article III, Section 5, of the Bylaws.

R. O. Beightol, *University of Tulsa*
Edmund R. Blakeman, *Colorado School of Mines*
Robert R. Brooks, *Colorado School of Mines*
W. J. Busteed, *Colorado School of Mines*
Raymond E. Doan, *University of Utah*
Howard Fleming, *University of Tulsa*

Simha Golosovker, *University of Tulsa*
Charles D. Hachenberg, *University of Tulsa*
Henry M. Hobart, Jr., *University of Tulsa*
Jason S. Johnson, *Colorado School of Mines*
William Kerr, *Colorado School of Mines*
Milton H. Lea, *University of Tulsa*
Howard W. Leaf, *Colorado School of Mines*
Don R. Mabey, *University of Utah*
Theodore R. Madden, *Massachusetts Institute of Technology*
Richard Miller, *Colorado School of Mines*
John Petrocco, *Colorado School of Mines*
James B. Sheehan, *Colorado School of Mines*
R. C. Siegfried, *Colorado School of Mines*
Robert J. Strozier, *University of Oklahoma*
Tom Teegarden, *University of Tulsa*
Frank P. Troseth, *Colorado School of Mines*
Boris Voukovitch, *Colorado School of Mines*
John J. Wallace, *Colorado School of Mines*
Andrew Wolikowski, *Colorado School of Mines*

MEETINGS OF THE LOCAL SECTIONS

DALLAS GEOPHYSICAL SOCIETY

September 22, 1949

A Single Boat Seismograph System, L. C. Paslay, Marine Instrument Company. This paper described marine instrumentation, equipment and operating techniques used successfully in off-shore operations in the Gulf of Mexico. The paper, which was profusely illustrated with color slides and movies, was well received, and was followed by an interesting discussion period.

November 17–18, 1949—Regional Exploration Meeting of S. E. G.

Dallas Geophysical Society

President: O. C. Clifford, Jr.
1st Vice-Pres.: D. Ray Dobyns
2d Vice-Pres.: H. C. McCarver
Sec.-Treas.: T. R. Shugart

Fort Worth Geophysical Society

President: Robert E. Klabzuba
Vice-Pres.: V. Robert Kerr
Sec.-Treas.: R. H. Dana

Tulsa Geophysical Society

President: W. T. Born
1st Vice-Pres.: E. M. McNatt
2nd Vice-Pres.: N. J. Christie
Sec.-Treas.: N. R. Sparks

Ark-La-Tex. Geophysical Society

Pres.: Carl L. Bryan
Vice-Pres.: Richard Brewer
Sec.-Treas.: Jackson S. Young

REGIONAL MEETING COMMITTEES

Publicity: T. R. Shugart, Chairman, Ark-La-Tex; W. W. Clark
Advertising and Finance: C. J. Donnally, *Chairman*
Entertainment: H. O. McCarver, *Chairman*
Arrangements: A. E. McKay, *Chairman*
Program: D. Ray Dobyns, *General Chairman*
Dallas: E. D. Alcock, H. L. Cobb, C. G. Dahm, Patrick E. Haggerty, Wm. B. Heroy, Sr., R. A. Stehr
Fort Worth: Sidon Harris, *Chairman*, Ray Dudley, S. K. Steenbergh, James L. Morris
Tulsa: E. M. McNatt, *Chairman*
Ark-La-Tex: Richard Brewer, *Chairman*

I

GEOLOGIC RESPONSIBILITY IN SEISMIC EXPLORATION

By B. W. Beebe

The primary responsibility in any exploration program with the object of locating commercial deposits of petroleum is and must be geological. Geologists as a group have failed to recognize and

assume this responsibility insofar as geophysical prospecting is concerned. Despite the fact that many geologists have successfully entered the field of geophysics, exploration geologists have not as a group assumed the responsibility for correlating their work with the work of geophysicists. Although this paper deals primarily with seismic prospecting, the same direction, cooperation and integration is necessary in any geophysical program employing any technique. The fundamental problem is the interpretation of physical observations in terms of earth science.

The thesis of this paper is that the primary responsibility in exploration is geological and responsibility of the geophysical department or contractor is limited to three essentials:

1. To furnish the best, most modern and sensitive instruments available to perform the specific task.
2. To furnish skilled, efficient and experienced personnel to operate and maintain the equipment.
3. To furnish skilled and experienced technical and supervisory personnel to make necessary computations, preliminary interpretations and working with the geologist, arrive at an integrated interpretation on which a recommendation can be based.

All other responsibility must be assumed by the geologist. It is mandatory that he have a thorough understanding of the principles, problems, procedure and limitations of seismic exploration. It is not advocated that the geologist invade the field of the geophysicist, but if he is to intelligently appraise and use the results he must thoroughly understand their source and inherent strength and weakness. The need for this understanding is becoming more necessary as we are forced to prospect more marginal areas, areas where data are difficult to secure and interpret, and for prospects where the results are near the limit of accuracy.

II

THE LOWER AND UPPER CRETACEOUS GEOLOGIC HISTORY OF NORTH LOUISIANA AND SOUTH ARKANSAS

By T. H. Philpott

This article describes in a general way the events that have transpired in geologic time throughout Lower and Upper Cretaceous Periods of the Mesozoic era in north Louisiana and south Arkansas. The significance of certain structural elements, such as the Ouachita Mountains, Monroe Uplift, Sabine Uplift, Desha Basin and the Interior Salt Dome Basis is discussed.

The pre-lower Cretaceous unconformity and the Pre-Upper Cretaceous unconformity are illustrated by maps showing the areal distribution of formations below this surface. Palinspastic maps are used to show the distribution of Lower Cretaceous and Upper Cretaceous upon these unconformities. The regional structure is delineated on top of the Upper Cretaceous and base of the Ferry Lake Anhydrite contoured with an interval of 1,000 feet.

Isopachous maps of the Upper Cretaceous and Lower Cretaceous tend to show depo-centers as well as areas receiving little sediment. Stratigraphic and structural cross sections A-A′, F-F″, G-G″, and H-H″ are included to emphasize pertinent stratigraphy and the importance of the unconformities at the base of the Upper and Lower Cretaceous.

III

THE PART HELICOPTERS ARE PLAYING IN GEOPHYSICAL EXPLORATION

By E. Gustafson

Eighteen months of research and development have conclusively proven that helicopters are playing an important part in Gravity and Seismic operations in remote areas, such as Southern Louisiana marshlands, jungle and mountainous areas where transportation is a difficult problem. Airborne Gravity and Seismic operations are successfully being carried on with resulting increased production and lowered costs. Discussions on techniques used in Gravity and Seismic airborne operations, plus

a film showing actual field operations as well as flight performance, load carrying abilities, landing areas, weather restrictions and maintenance requirements for mobile operations and the possible use of the helicopter in the oil industry, will be discussed in detail.

IV

THE APPLICATION OF ELECTRIC LOGGING TO GROUND-WATER EXPLORATION

By P. H. Jones and T. B. Buford

A method is described for determination of the quality of ground water in granular aquifers penetrated by rotary drilled holes electrically logged. Conventional techniques of electric-log interpretation, to determine true bed resistivity from apparent resistivity values, are briefly described; the physical characteristics of granular aquifers which influence bed resistivity are discussed, with special reference to the formula developed by Archie; and a method for converting water-resistivity values into hypothetical chemical analyses is explained.

The objective of the method is to narrow the limits of error in quality-of-water estimates based upon electric logs. Water-well contractors are fully aware of the risks attendant in making drill-stem tests in open hole, which is the method now employed to obtain representative samples of formation water. Packer failure results in contaminated samples; hole collapse may mean loss of drill stem, screen, and the hole. In the Gulf Coast where water-well tests range in depth from 100 to 3,000 feet, methods which will eliminate at least a part of the need for drill-stem tests deserve consideration.

The paper deals also with methods of determining formation porosity in situ, which is an important factor in salt-water-encroachment problems.

V

A SINGLE BOAT SEISMOGRAPH SYSTEM

By L. C. Paslay

A seismograph system specifically designed for single boat operations in offshore tideland areas is described. The use of pressure operated detector "streamers" permits continuous forward motion of the ship resulting in practical operation in any normal weather conditions. Geographical location of the actual shot points is provided to great accuracy by means of a "radio Sonobuoy" system of surveying. Operational data over a full year's time is given.

VI

SNELL'S LAW, EVOLUTES AND INVOLUTES

By M. M. Slotnick

Rays emanating from a point source in a medium are assumed to be refracted at a plane interface between that medium and another, in accordance with Snell's Law. In any plane section, the refracted rays then form, analytically, a one-parameter family of lines which has an envelope. The envelope is the evolute of the "wave" fronts in the second medium. The evolute is found to be the evolute of an ellipse, or hyperbola, according as the index of refraction is greater than, or less than, unity, respectively. Since, analytically, one of the family of wave fronts is an ellipse, or hyperbola, a means is provided for graphically determining the refraction of the rays at the interface and drawing the corresponding "wave fronts."

VII

EXAMPLES OF AEROMAGNETIC SURVEYS AND THEIR INTERPRETATION

By Joseph A. Sharpe

Following a brief exhibit of the precision and freedom from surface effects displayed by aeromagnetic data, examples are given of aeromagnetic surveys over known structures in provinces in

which the sedimentary section is thin, of moderate thickness, and of great thickness, and the interpretation of these examples is discussed.

VIII

THE PHOTOGRAPHIC SURVEY CORPORATION'S AIRBORNE PROFILE RECORDER

By B. I. McCaffrey

The Photographic Survey Corporation, Toronto, has produced a number of Airborne Profile Recorders for topographic survey. These are precision radar instruments which, tests have proven, are capable of measuring with the accuracy required for good surveying.

The technique employs an aircraft flying at constant pressure height above sea level, while a radar altimeter measures the terrain clearance below. A recording type ammeter replaces the familiar cathode ray tube of the usual radar set and records continuously the radar signals. A permanent scale, drawing of the ground elevation profile along the flight track is thus obtained.

Correlation between profile and map position is accomplished by synchronized vertical photography.

Compensation for deviations from a level datum is automatic and the resulting graphic record is a true copy of the topographic details.

Considerable amounts of field work have been carried out by the P.S.C. and by the Canadian Government using these instruments, and practical experience has demonstrated their value as survey tools.

IX

PUBLIC RELATIONS IN GEOPHYSICAL PROSPECTING

A Symposium prepared by the Fort Worth Geophysical Society

A comprehensive statement of existing problems in public relations as applied to geophysical exploration is enumerated.

Several suggestions falling into two major classifications are offered to alleviate these existing problems. The first group includes suggestions to improve field operations from the standpoint of public relations while the second group includes suggestions to stimulate and encourage a broader general educational program of the public at large with reference to the value of geophysical operations in their towns and communities.

X

CAN REEFS BE FOUND WITH THE SEISMOGRAPH?

By E. D. Alcock

This article answers the question asked by the title in the affirmative. The various physical characteristics of bioherm type reefs are discussed and the manner in which they lend themselves to the seismic method of geophysical exploration.

XI

STRUCTURE FORMING ROLE OF REEF MASSES IN WEST CENTRAL TEXAS

By Gerson H. Brodie

The author develops a theory of draped sediments, rather than tectonic influences, which may prove of interest in oil search. Slides of maps and cross sections through numerous fields in the West Central Texas Area will be presented and discussed.

XII

SEISMIC EXPLORATION FOR REEFS HAS NO UNIQUE SOLUTION

By Ray Dobyns

This paper will give a discussion of the problems encountered in conducting a seismic survey of the Jameson Field. There will be a discussion of the methods used to obtain the best data, the method of computing and interpreting, and of records, time sections and maps.

Records obtained in the Snyder Area of Scurry County will be shown. Problems of velocity as related to the geologic section in this area will be discussed. Records near high producers and near edge dry holes will be shown and discussed.

XIII

THE VEALMOOR FIELD, HOWARD AND BORDEN COUNTIES, TEXAS—A PENNSYLVANIAN REEF

By S. J. Taylor and H. C. McCarver

The Vealmoor Field of northern Howard County and southern Borden County produces from reef limestone of Upper Pennsylvanian age. The field was discovered in January, 1948, by Seaboard Oil Company of Delaware, Comanche Corporation, and Brown Brothers as a result of seismic exploration. Subsurface and seismograph maps and cross sections will be presented showing the relationship of structure and sedimentation to the reef limestone.

XIV

REFLECTION SHOOTING IN THE NORTH SNYDER AREA, SCURRY COUNTY, TEXAS

By Neal Clayton

Development of the North Snyder Area began in November, 1948 when the Standard of Texas completed their No. 1-2 Jessie Brown in Section 440, H. & T.C.R.R., Block 97. Interest in the area was increased when the Sunray *et al.*, completed their No. 1 R. B. Brown in April, 1949, thereby extending the field three miles south.

Electric log and seismic correlations at several points across the field will be offered to illustrate the problems involved. Specimens records will be introduced to show that at least in certain parts of the field, a reflection is obtained from the top of the reef.

The effect of surface conditions on record quality will be discussed and some suggestions made for this type of exploration.

XV

THE CASE HISTORY OF THE HENRY COMPTON BLOCK, STEPHENS COUNTY, TEXAS

By D. B. Campbell, Jr., G. H. Harrington, Jr., and R. J. Dilger

This paper presents the geophysical and geological investigations leading to the discovery of oil production from a reef development under the Henry Compton Block, a part of the Stephens County Regular Field in southwestern Stephens County, Texas. Seismic and subsurface maps, cross sections and production data are presented.

XVI

GRAVITY SURVEY REDWATER FIELD, ALBERTA, CANADA

By John Bible

This paper is a discussion of the gravity results of a survey of the Redwater Field, Alberta, Canada. Topographic maps will be shown. A subsurface map will be shown and gravity maps of the area shown and discussed.

XVII

A PROGRESS REPORT ON DEVONIAN REEF EXPLORATION IN CANADA

By Wentworth J. Tellington

The problems of surface and subsurface as related to seismic problems in Redwater and other areas of Canada will be discussed.

FORT WORTH GEOPHYSICAL SOCIETY

August 15, 1948

Smoker and informal discussion.

September 27, 1948

Recent and Current Highlights of the Geophysical Exploration, M. M. Slotnick, Humble Oil & Refining Company.

October 25, 1948

Public Relations, Paul Cain, Oil Industry Information Committee.

November 29, 1948

Geophysical History of the Salem Oilfield, A. A. Hunzicker, The Texas Company.

December 22, 1948

In lieu of the meeting scheduled for December 27, a cocktail hour was held.

January 31, 1949

Selling Geophysical Interpretation, R. C. Forman.

February 22, 1949

Limitations of Seismic Exploration for Limestone Reefs, Paul E. Purcell.

March 28, 1949

Progressive Detonation of Multiple Charges in a Single Seismic Shot, Lorenz I. Shock, National Geophysical Company.

April 25, 1949

Mr. H. E. Itten presented a report on the activities and status of the public relations project.

May 27, 1949

Responsibilities of the Geologists in Conducting Geophysical Surveys, B. W. Beebe, Anderson-Pritchard Oil Corp.

July 25, 1949—Special Meeting

Mr. E. J. Stulken discussed briefly the activities of the Southern Seismic Well Shooting Association.

September 26, 1949

Multiple Reflections, R. D. Bryan.

SOCIETY OF EXPLORATION GEOPHYSICISTS
HOUSTON SECTION

October 14, 1949

Geophysical Studies of Taku Glacier and Juneau Ice Field in Alaska, Thomas C. Poulter, Stanford Research Institute.

PACIFIC COAST SECTION
SOCIETY OF EXPLORATION GEOPHYSICISTS

November 17–18, 1949—Annual Regional Meeting

I

RECENT DEVELOPMENTS IN GEOPHYSICAL EXPLORATION EQUIPMENT

C. H. Carlisle

A discussion of a series of slides showing several types of specialized geophysical exploration equipments and techniques used in present day field operations, as well as some of the types of equipment and techniques formerly used in the exploration program.

II

REFLECTED ENERGY VARIATIONS RESULTING FROM SMALL CHANGES IN SHOT HOLE AND SPREAD LOCATIONS

Carl H. Savit

Examples of seismograms and cross sections are presented to illustrate changes of considerable importance resulting from relatively minor displacements of shot holes and spreads. Records and cross sections are exhibited from continuous profiling lines which were shot from separate lines of shot holes on opposite sides of a single line of spreads as well as from lines which were shot from a single line of holes but which were recorded simultaneously on separate parallel spreads. A comparison of the results of conventional spread arrangements and of the parallel line or "H" spread technique as used in difficult areas is made.

III

WAVE VELOCITY IN THE EARTH'S CRUSTAL LAYERS

Beno Gutenberg

Earthquake waves in most continental areas indicate a velocity of the first arrival, not considering low velocity sediments, of 5.5–5.6 km/sec, which has been attributed to the so-called "granitic layer." On the other hand, in some of these areas, artificial explosions indicate velocities of 6 km/sec or even more for the top layers of the "basement complex." In order to bring findings from artificial explosions and earthquakes into agreement it is suggested that most "normal" shallow earthquakes originate at a depth of about 10 miles in a layer of relatively low wave velocity, while in the upper part of the so-called "granitic layer" longitudinal waves travel with velocities increasing from about 6 km/sec near the surface (with a sudden jump or gradually) to 6.5 or more, at a depth of about 10 kilometers. The bearings of these results on findings from field records, reflections from the "interior of the basement complex," and the importance of data from artificial explosions for the solution of these problems are discussed.

IV

SEISMIC STUDIES OF THE PACIFIC OCEAN FLOOR OFF CALIFORNIA

Russell W. Raitt

Refraction and reflection of sound waves by the ocean bottom is being studied off California. Charges of TNT are used as sources and the reflected and refracted waves rae received with pressure-sensitive crystal hydrophones.

In general, bottom echoes from the deep ocean are confused by topographic effects and are not easily interpreted in terms of bottom structure. Greater success is achieved with refraction technique, and most of the study has been spent using this method.

By giving careful study to the problem of the proper depths of shot and hydrophone and to methods of hydrophone suspension, it was found possible to record the basement wave consistently at distances of 30 miles with 50 pound charges. As this size of charge is easily handled, the work proceeds rather rapidly and in an ordinary day's operation 50 miles of refraction profile, with shots at one mile intervals, is recorded. Examples will be shown of profiles recorded in 2,000 fathoms depth beyond the continental slope and within the continental borderland inside the continental slope.

This work represents one of the results of research carried out under contract with the Bureau of Ships, Navy Department.

V

HIGHLIGHTS OF CALIFORNIA OFF SHORE SEISMIC SURVEYING

E. M. Curry

The purpose of this paper is to describe in only a general way, for the benefit of those of the industry who have had no previous contact with this work, the operations and problems of marine seismic surveys along the California coast, with occasional brief comparison with marine surveying in the Gulf of Mexico.

VI

OFF SHORE SEISMIC PROBLEMS AFFECTING GEOLOGIC EVALUATIONS

Curtis H. Johnson and Robert B. Galeski

VII

MAGNETIC CORE ORIENTATION

N. A. Riley

VIII

LENGTHENING OF SEISMIC PULSES PROPAGATED IN TWO SPACIAL DIMENSIONS

C. Hewitt Dix

Results of mathematical studies show that an elastic pulse of any type propagated outwards from a central axis has the physical property that some of the energy must always be propagated backwards toward the source. This backward propagation lengthens any pulse, however short initially, so that it has a long tail. Many features of the propagation of seismic pulses are affected by this backward propagation.

November 18, 12:15.—S.E.G. Luncheon.

Short lecture by Professor Beno Gutenberg, "Direction of Fault Movements in Southern California as indicated by Seismograms of Earthquakes."

The most recent results on this were briefly reported by Mr. Peter Dehlinger after Professor Gutenberg's presentation.

ARK-LA-TEX GEOPHYSICAL SOCIETY

September 20, 1949

This luncheon, the first meeting of the 1949–50 year, was held in the main dining room of the Caddo Hotel. Approximately 35 members and guests were present.

Mr. Carl Bryan, President, presided, and conducted a brief business meeting during which mention was made of conventions to be held this Fall in Biloxi, October 12–14 and in Dallas, November 16–18, in which the Ark-La-Tex Geophysical Society is to take part. Mr. Bryan appointed Mr. W. W. Clark to take charge of advertising sales for the Ark-La-Tex Society.

As the feature of the meeting a film, "Shallow Water Shooting on the Louisiana Coast" was shown through courtesy of Atlantic Refining Company. The companion picture on deep water shooting will be shown at a later meeting.

The meeting was adjourned following a statement by the treasurer indicating his willingness to accept dues for 1949–50.

October 20, 1949—Luncheon Meeting

Oil of Peru, a color-sound film produced by the Standard Oil Company of New Jersey.

GEOPHYSICAL SOCIETY OF TULSA

October 13, 1949

The regular monthly meeting of the Geophysical Society of Tulsa was held on Thursday, October 13, 1949, at 7:00 P.M. in Lorton Hall on the University of Tulsa Campus. Two hundred members and guests were present. Mr. W. T. Born presided.

Dr. E. M. McNatt, Carter Oil Company, was chairman of a symposium on "Seismic Airshooting." The following participated in the symposium:

Mr. C. M. Ross—Amerada Petroleum Corporation
Mr. E. J. Handley—Century Geophysical Company
Mr. John W. Daly—Honolulu Oil Company
Mr. D. R. Dobyns—Magnolia Petroleum Company
Mr. W. O. Novelly—Republic Exploration Company
Mr. R. A. Peterson—United Geophysical Company
Dr. T. C. Poulter—Stanford Research Institute

The speakers presented records and data comparing in-hole and air shots for various areas, from Alaska and Canada to the South Polar region. Dr. Poulter showed records of the type of pulse initiated by air shooting and the variation of the frequency of that pulse as "controlled" by the shot pattern.

Dr. Dan Silverman, Chairman of the Frequency Allocation Committee, announced that the F.C.C. has discontinued the 1602 radio frequency heretofore allotted to geophysical crews. If demand proves sufficient, the FCC will allocate a 1614 band to the industry in place of the 1602. Geophysicists interested in reserving the 1614 band for their operations should write at once to Joseph E. Keller, c/o American Petroleum Institute, 1625 Kay St., N.W., Washington, D. C., who will present such letters to the Commission.

November 10, 1949

Error Studies as Applied to Geophysical Field Data, John M. Crawford, Continental Oil Company.

This paper attempts to present practical methods for field data which will give both quantitative and graphic presentation. Graphic tabulation methods, easily adapted to use by the field crew, show at a glance the performance characteristics of gravity meters and elevation and location surveys. Further study of the graphic charts may be made to yield mathematical concepts of accuracy. A study, seeking to show the individual's ability to estimate tenths of a scale division, is presented. Variations between individuals and variations in work of the same person over a period of years are found interesting. It is possible that the charts obtained in these studies may be of use in improving the ability of the observer to read scales accurately.

UNIVERSITY OF TULSA STUDENT GEOPHYSICAL SOCIETY

October 12, 1949

The Student Geophysical Society of the University of Tulsa in conjunction with the Geology Club sponsored a lecture by Dr. Thomas C. Poulter, scientist and explorer, of Stanford Research Institute on October 12, 1949.

Dr. Poulter discussed and showed slides of his recent work of this past summer on Taku Glacier in Alaska. Approximately 200 University students and guests from downtown attended the lecture.

Seismic measurements of ice thicknesses was the primary object of Dr. Poulter's research. The technique and the portable equipment used in these measurements were of special interest to students of geophysics. Fundamental research in the Poulter Process of air shooting and in the study of wave motion was part of the summer program.

John B. Etnyre, President
University of Tulsa
Student Geophysical Society

PROPOSAL FOR INCREASE IN MEMBERSHIP DUES AND SUBSCRIPTION PRICES

At the joint council meeting held during the 1949 annual meeting of the Society in St. Louis, it was reported that the Society sustained a net operating loss of $4,313.29 during the 1948 calendar year. This loss is shown by the Treasurer's Report published in *Geophysics*, Volume XIV, No. 3, July, 1949, pages 465 to 469. The Council instructed the Executive Committee to submit its recommendation for an increase in membership dues to forestall the possibility of future losses.

A study of Income versus Expense and Publication Costs for the current and preceding two years served as a guide for estimating the Income and Expenses for 1950 and 1951. Based on this study, a net loss of $3,284.89 for 1950 and a net loss of $5,759.79 for 1951 is anticipated.

To offset these anticipated losses, the Executive Committee recommends an increase of 50% in the annual membership dues. It is estimated that the resulting increase in income in 1951 will offset the estimated loss to the extent that a safe net profit of $2,825.71 will result.

The revised schedule to take effect January 1, 1951, is given below:

	1948	*1951*
Active Membership	$5.00	$7.50
Associate Membership	5.00	7.50
Student Membership	3.00	4.50
Subscriptions	6.00	9.00

PROPOSED AMENDMENTS TO THE BY-LAWS

1. Article IV, Section 2 of the By-laws shall be amended to read:

   "The annual dues of an Active or Associate Member of the Society shall be seven dollars and fifty cents ($7.50), which includes the cost of one subscription to the Society's Journal."

2. Article IV, Section 3 of the By-laws shall be amended to read:

   "The annual dues of a student member of the Society shall be four dollars and fifty cents ($4.50), which includes the cost of one subscription to the Society's Journal."

The above amendments are proposed in accordance with Article XVII, Section 1 of the Constitution: "The Council shall make such By-laws not in conflict with the Constitution, as it may deem necessary for the proper government of the Society. The Council may amend the By-laws at the annual joint meeting by an affirmative vote of two-thirds of the members of the incoming Council present. All proposed amendments must, however, be published in the Society's Journal before being submitted to the Council."

Under Article XVI of the Constitution (published in *Geophysics*, Volume XIV, No. 2, 1949, page 214) all actions of the council are subject to review by the members. The above amendments to the By-laws will be submitted to the Council at the 1950 annual meeting.

October 29, 1949 EXECUTIVE COMMITTEE

ANNOUNCEMENTS

ANNUAL MEMBERSHIP LIST

Members of the Society of Exploration Geophysicists are requested to examine the listing of their names in the membership list published in *Geophysics*, Vol. XIV, No. 2 (April, 1949). Any inaccuracies in that listing must be reported to the business office of the Society not later than February 1, 1950 to avoid repetition in the list to be published in April, 1950 *Geophysics*.

DISTINGUISHED LECTURE TOUR

Dr. Merle A. Tuve, and Dr. Howard Tatel, both of the Carnegie Institution of Washington, will speak during January in Houston, Shreveport, Dallas, and Tulsa to sections of the Society of Exploration Geophysicists according to Francis F. Campbell, Chairman of the Distinguished Lectures Committee. The talks are the first of the Distinguished Lecture Series of the national society. The two physicists will collaborate on the lecture, subject of which will be "Current Magnetic and Seismic Studies of the Carnegie Institution of Washington." The lecture will be illustrated.

Schedule of the lectures is as follows: Houston, January 16; Shreveport, January 18; Dallas, January 19; and Tulsa, January 23. The Ft. Worth and Dallas sections will meet jointly at Dallas for the talks.

The lecture will describe recent studies of terrestrial magnetism, with particular reference to the remanent magnetism of rocks. The orientation of original magnetism of rocks permits tracing of the shift of the earth's magnetic field during geologic time. A part of the lecture will tell of detailed studies of earth structure made from 140 successful seismic tests. Three years ago Dr. Tuve obtained a stock of high explosives from the Navy and used them for large seismic blasts. The primary aim of the seismic studies has been the obtaining of information on the roots of mountain chains and the development of theories of Appalachian structure.

Dr. Tuve, who is director of the Department of Terrestrial Magnetism of Carnegie Institution, was responsible for the group which, during the war developed the proximity fuse that causes a shell to burst close to a target in the air. The fuse had a marked effect on the outcome of the late war, and Tuve received the Presidential Medal for Merit in 1946 for his war effort contributions. In 1931 he shared the award of the American Association for the Advancement of Science. Dr. Tuve's contributions to science include significant researches in terrestrial magnetism, seismology, nuclear physics, high voltage apparatus, and biophysics. He is a member of the U. S. National Commission for UNESCO. He was one of the first physicists to measure the height of the ionosphere and is known as a pioneer of radar development. Dr. Tuve is editor of the newly instituted Journal of Geophysical Research. Dr. Tatel has worked with Dr. Tuve for a number of years and at present directs the Carnegie Institution program on the earth's crust. Dr. Tatel was one of the first investigators of the magnetic moment of the neutron at Stanford University, and was a member of the proximity fuse team throughout the war. He has worked for Dr. Tuve for a number of years and at present directs the Carnegie Institution program on the earth's crust.

ANNOUNCEMENT OF THE TWENTIETH ANNUAL MEETING

The Society of Exploration Geophysicists will hold its twentieth annual meeting concurrently with the annual meetings of the American Association of Petroleum Geologists and the Society of Economic Paleontologists and Mineralogists April 24–26, 1950 at the Stevens Hotel in Chicago. Official notices of the meeting were mailed to the members last December so that they might plan their attendance and request reservations by mailing the Stevens Hotel room-request card enclosed with the announcement.

In addition to the regular business and joint session, the program of the S.E.G. is arranged to present technical papers on instruments and interpretation, case histories, and a session on "The Application of Geophysics to the Discovery of Reefs."

George E. Wagoner, Drawer 1739, Shreveport, Louisiana, is chairman of the program and arrangements committee. Members planning on submitting papers should notify the sectional committee members about the title and length of paper; and abstracts, typewritten and in triplicate should be in the hands of the chairman on or before February 1.

The joint societies, through their program chairmen, have appointed Gail F. Moulton of the Chase National Bank, New York City, as chairman of a committee to secure outstanding speakers for a joint non-technical program.

Information concerning exhibits, scientific and commercial, may be obtained from A.A.P.G. Headquarters, Box 979, Tulsa 1, Oklahoma. Additional room-request cards may be obtained from the Business Office of the S.E.G.

PERSONAL ITEMS

ROBERT L. CRAIG, formerly gravity meter party chief with The Carter Oil Company, is now with Standard Vacuum Oil Company, Sungei Gerong, Palembang, Sumatra. Mr. Craig announces the birth of a daughter, Christine Monnier Craig, on October 1, 1949, and he is looking forward to the time when the young lady, her mother and three year old brother can make a trip half way around the world to join him in Sumatra.

JOHN O. GALLOWAY has been chosen temporary chairman of the Western Canada Geophysical Society, the name applied to the newest local section of S.E.G. now being organized in Calgary, Alberta, Canada.

R. L. GALLOWAY, party chief for The Texas Company, has transferred from Jackson, Miss. to Laurel, Miss.

ERNEST A. KIESLER, District Supervisor for Geophysical Service, Inc., on the Pacific Coast, has moved to Calgary, Alberta, Canada, according to an announcement by Dr. H. B. PEACOCK, president of the company. Kiesler will be associated with CHAS. M. MOORE, JR., GSI's Canadian Representative, and will retain the position of District Supervisor. Also in the Canadian Staff are: RAY H. WRIGHT, Assistant Supervisor; T. A. HALBROOK, Seismologist, and ART JENSEN, Surveying Supervisor.

Announcement of the promotion of H. W. BROWN, to assistant chief geophysicist of The Carter Oil Company was made today by H. F. Moses, vice president in charge of exploration. Until recently, Brown served as supervisor of foreign geophysical operations.

Brown, a graduate of Louisiana Polytechnic Institute, Ruston, Louisiana, came to Carter's geophysical department in 1935. He has been active in several professional societies and is a member of the American Association of Petroleum Geologists and the Society of Exploration Geophysicists.

R. F. WEICHERT, formerly on loan to the Imperial Oil Company, Ltd. from the Standard Oil Company (New Jersey), will assume the position of supervisor of foreign geophysical operations.

Weichert, a graduate of Rice Institute, Houston, Texas, first worked for The Carter Oil Company in 1935 and was transferred to Standard Oil Company (New Jersey) after his return from Europe in 1940. He is a member of the American Geophysical Union and the Society of Exploration Geophysicists.

R. C. CLARK, who has recently served as supervisor of geophysical operations in Carter's Northwest Division, will become Assistant Supervisor of foreign operations.

Clark, who was graduated from the University of Nebraska, Lincoln, Nebraska, has been with Carter since 1935. He is a member of the Society of Exploration Geophysicists.

C. N. HURRY, will become supervisor of domestic geophysical operations. Hurry has been associated with geophysical work in the United States and Canada. He first worked for Carter in 1935. He is a member of the Society of Exploration Geophysicists and the American Association of Petroleum Geologists, and is a graduate of the Colorado School of Mines, Golden, Colorado.

WILLIAM J. ROONEY, a Staff Member of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, died at Tooele, Utah, on August 31, 1949, at the age of 59, following an automobile accident the night before. He was en route to his office in Washington, D. C. from California, where he had been conducting special seismic investigations for the preceding two months.

Mr. Rooney joined the staff of the Department of Terrestrial Magnetism as an Electrical Engineer and Physicist in 1924. He conducted research work on earth currents and resistivity in this country, as well as in Australia, Guatemala, Peru, and Spain, and was considered an authority in this field. He was a co-developer of the Gish-Rooney method of electrical prospecting. More recently he had devoted his time to research in seismology. At the time of his death he was a panel member of the Research and Development Board. During the war he participated in the development of the VT fuse as a consultant with the National Defense Research Committee and directed a project for the Navy's Bureau of Ordnance at the Naval Ordnance Laboratory. He received the Naval Ordnance Development Award for this work. Prior to 1924 Mr. Rooney had been associated with E. I. Du Pont de Nemours and Company and the Bureau of Standards on ballistics research.

Mr. Rooney was born in Waltham, Mass., and received an A.B. degree from Boston College in 1912 and a B.S. degree from Massachusetts Institute of Technology in 1915. He was a member of the Cosmos Club and of several scientific societies..

A bachelor, he is survived by two brothers and two sisters. M. A. TUVE

STATEMENT OF THE OWNERSHIP, MANAGEMENT, CIRCULATION, ETC., REQUIRED BY THE ACTS OF CONGRESS OF AUGUST 24, 1912, AND MARCH 3, 1933

of GEOPHYSICS, published quarterly at Menasha, Wisconsin, for January, 1950

State of Oklahoma } ss.
County of Tulsa }

Before me, a Notary Public in and for the State and county aforesaid, personally appeared Colin C. Campbell, who, having been duly sworn according to law, deposes and says that he is the business manager of GEOPHYSICS, and that the following is, to the best of his knowledge and belief, a true statement of the ownership, management (and if a daily paper, the circulation), etc., of the aforesaid publication for the date shown in the above caption, required by the Act of August 24, 1912, as amended by the Act of March 3, 1933, embodied in section 537, Postal Laws and Regulations, printed on the reverse of this form, to wit:

1. That the names and addresses of the publisher, editor, managing editor, and business managers are: Publisher, Society of Exploration Geophysicists, Box 1614, Tulsa 1, Oklahoma; Editor, Richard A. Geyer, Box 2180, Houston 1, Texas; Managing Editor, Richard A. Geyer, Box 2180, Houston 1, Texas; Business Manager, Colin C. Campbell, Box 1614, Tulsa 1, Oklahoma.

2. That the owner is: (If owned by a corporation, its name and address must be stated and also immediately thereunder the names and addresses of stockholders owning or holding one per cent or more of total amount of stock. If not owned by a corporation, the names and addresses of the individual owners must be given. If owned by a firm, company, or other unincorporated concern, its name and address, as well as those of each individual member, must be given.) Society of Exploration Geophysicists (Inc.), Box 1614, Tulsa 1, Oklahoma; President, Andrew Gilmour, Box 2040, Tulsa 2, Okla.; Vice-President, George E. Wagoner, Drawer 1739, Shreveport, La.; Kenneth E. Burg, Secretary-Treasurer, 6000 Lemmon Ave., Dallas 9, Texas; L. L. Nettleton, Past President, 1321 Niels Esperson Bldg., Houston 2, Texas.

3. That the known bondholders, mortgagees, and other security holders owning or holding 1 per cent or more of total amount of bonds, mortgages, or other securities are: None.

4. That the two paragraphs next above, giving the names of the owners, stockholders, and security holders, if any, contain not only the list of stockholders and security holders as they appear upon the books of the company but also, in cases where the stockholder or security holder appears upon the books of the company as trustee or in any other fiduciary relation, the name of the person or corporation for whom such trustee is acting, is given; also that the said two paragraphs contain statements embracing affiant's full knowledge and belief as to the circumstances and conditions under which stockholders and security holders who do not appear upon the books of the company as trustees, hold stock and securities in a capacity other than that of a bona fide owner; and this affiant has no reason to believe that any other person, associaion, or corporation has any interest direct or indirect in the said stock, bonds, or other securities than as so stated by him.

5. That the average number of copies of each issue of this publication sold or distributed, through the mails or otherwise, to paid subscribers during the twelve months preceding the date shown above is ————. (This information is required from daily publications only.)

COLIN C. CAMPBELL (Signed)

Sworn to and subscribed before me this 20th day of September, 1949.

[SEAL] JEAN GRANT REAMES (Signed)

(My commission expires October 16, 1952.)

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Meetings on second Thursday, each month, October to May, inclusive, at 7:00 P.M. in Lorton Hall on University of Tulsa Campus. Visiting geophysicists are always welcome.

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Regular Meetings
8:00 P.M.
2nd Mondays

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Vice President Southern District: E. L. Erickson, Continental Oil Co., Los Angeles, California
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Informal Luncheon, Tuesdays, Bakersfield Inn, Bakersfield, and third Thursday each month Hotel Clark, Los Angeles. Annual Spring Meeting in Bakersfield. Annual Fall Meeting in Los Angeles.

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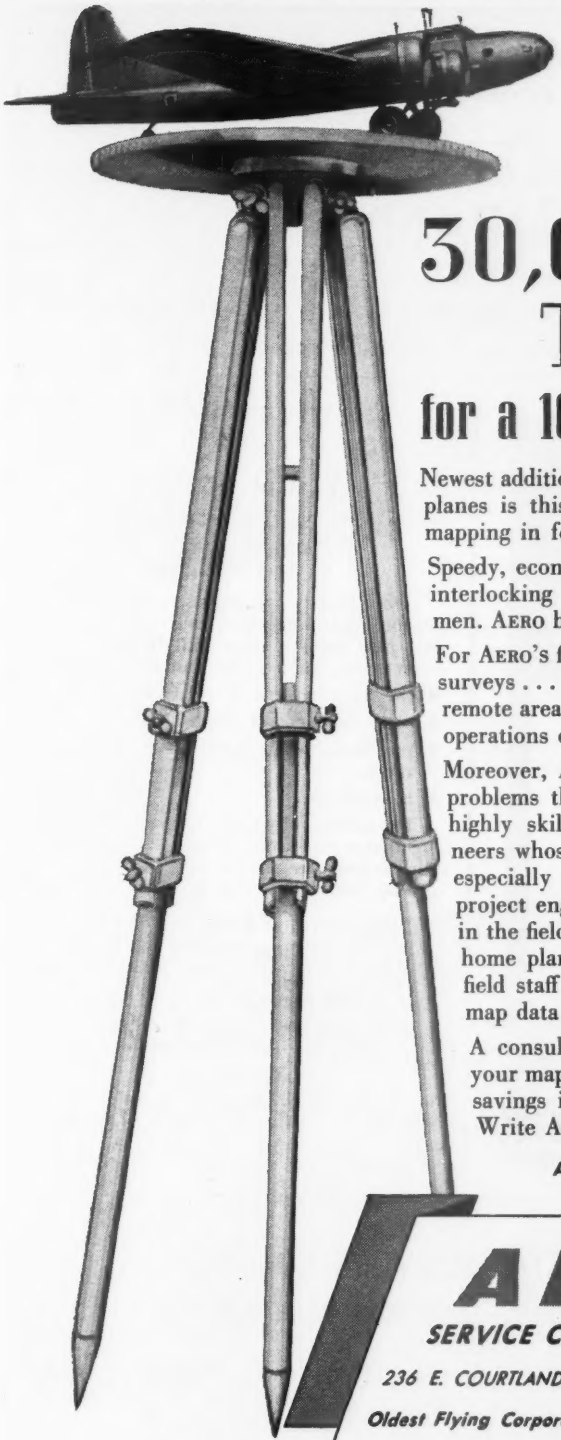

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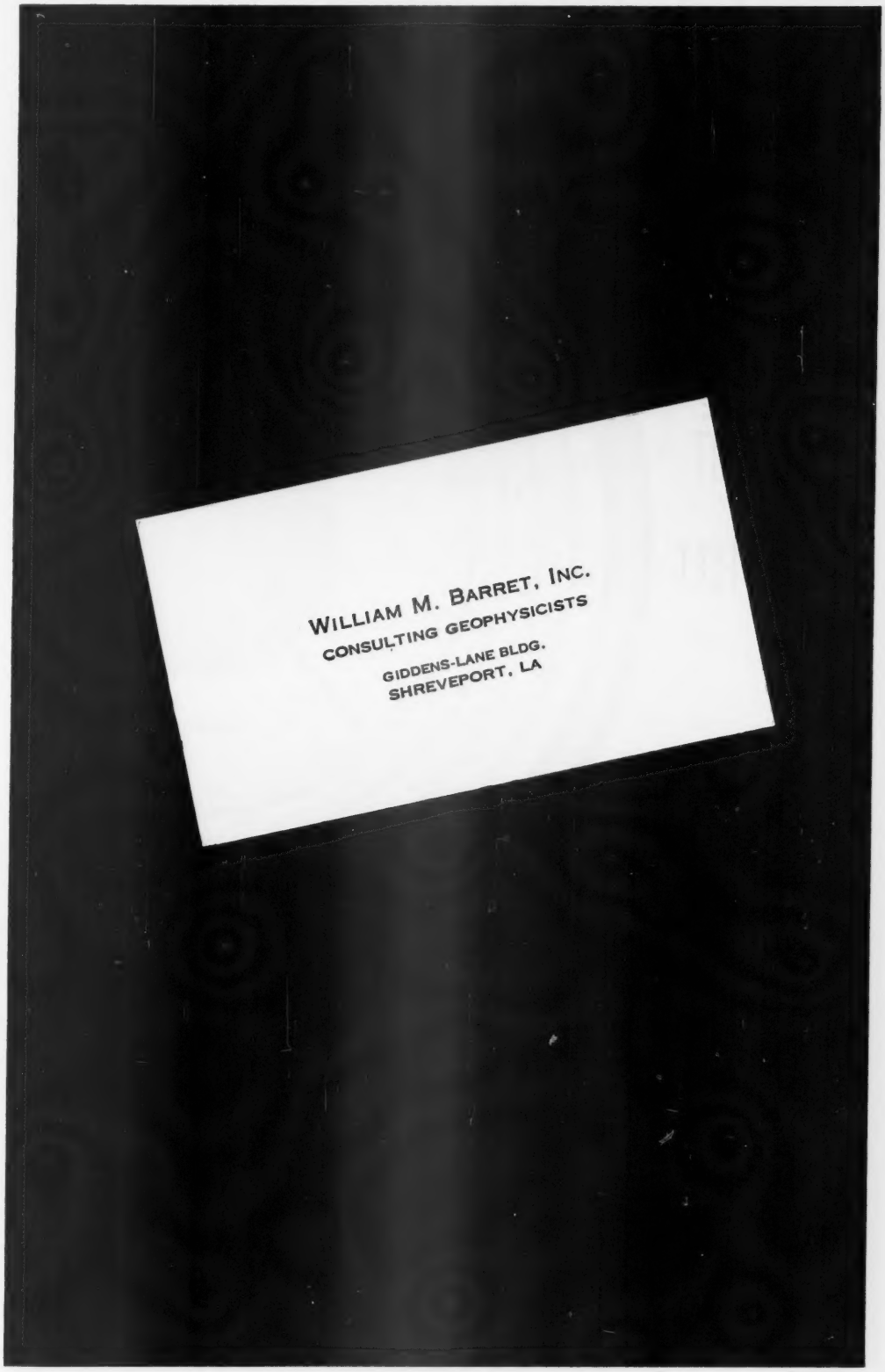

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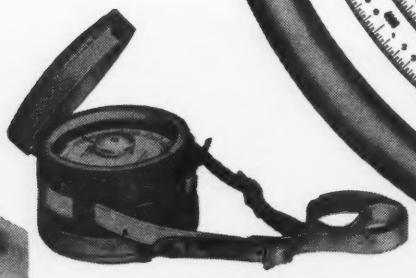

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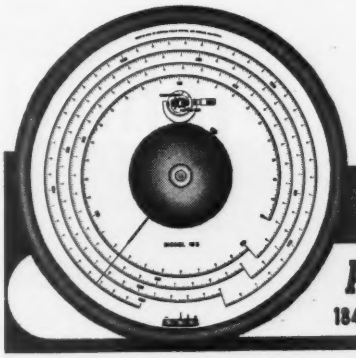

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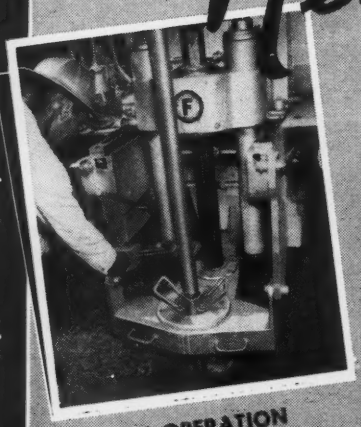

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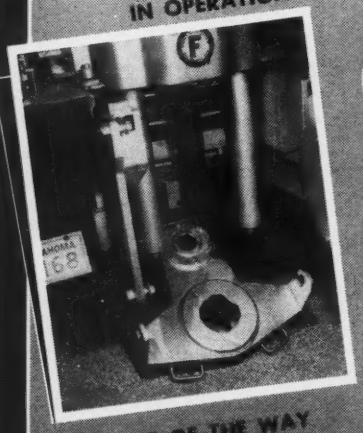

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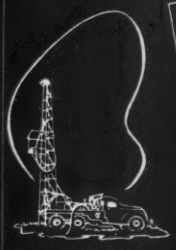

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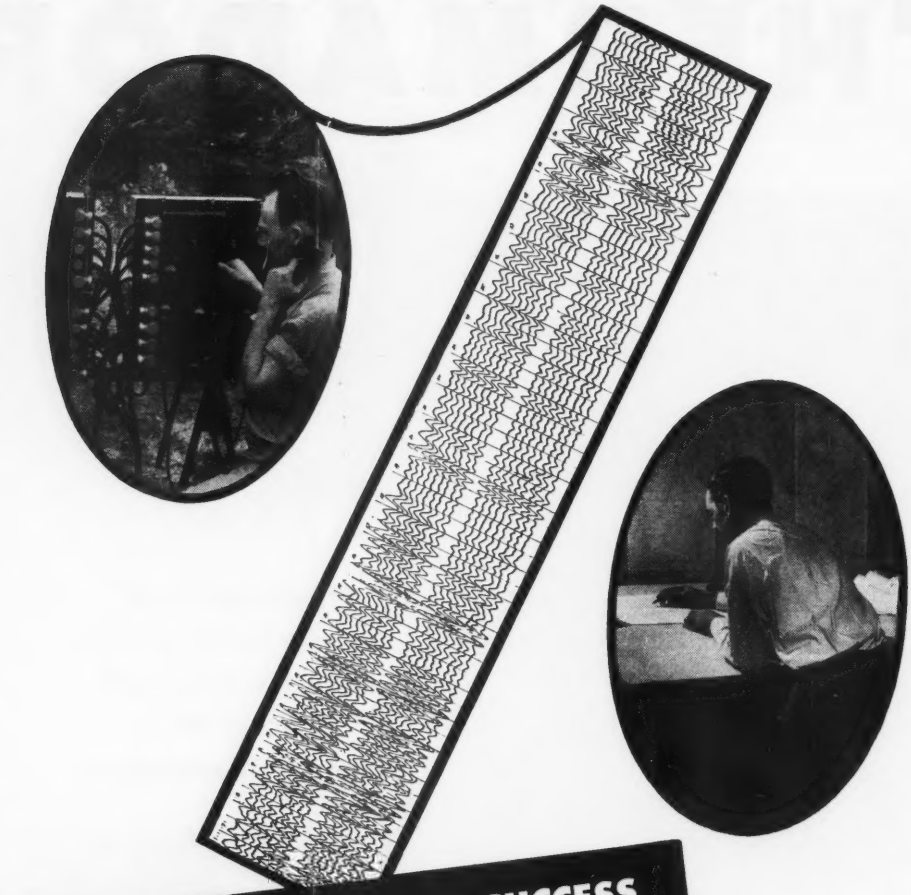

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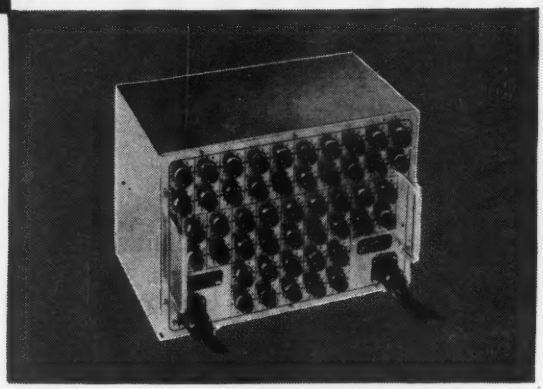

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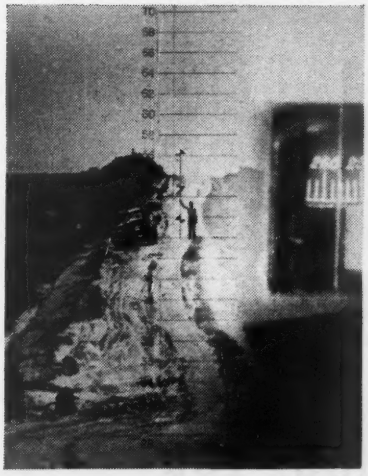

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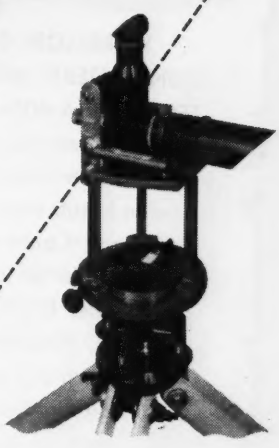

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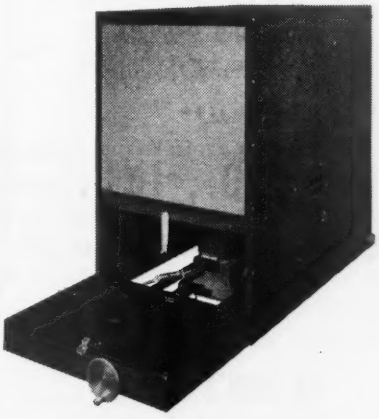

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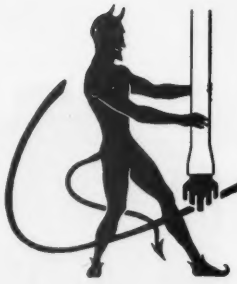

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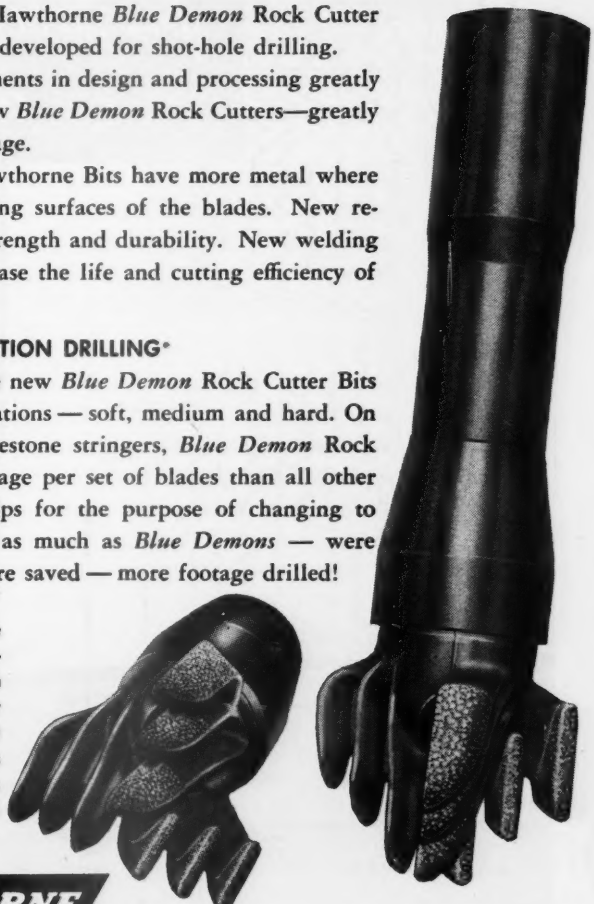

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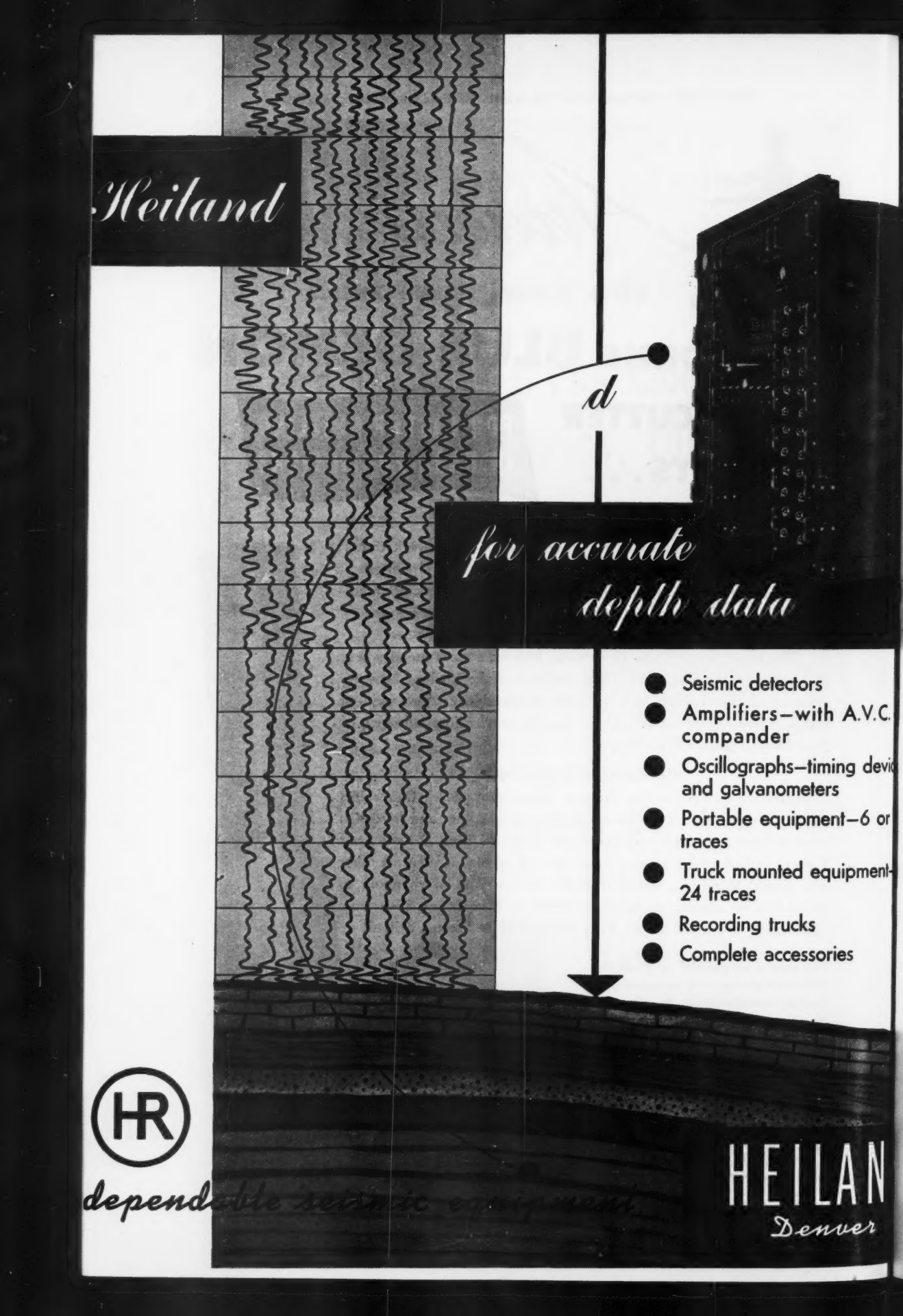
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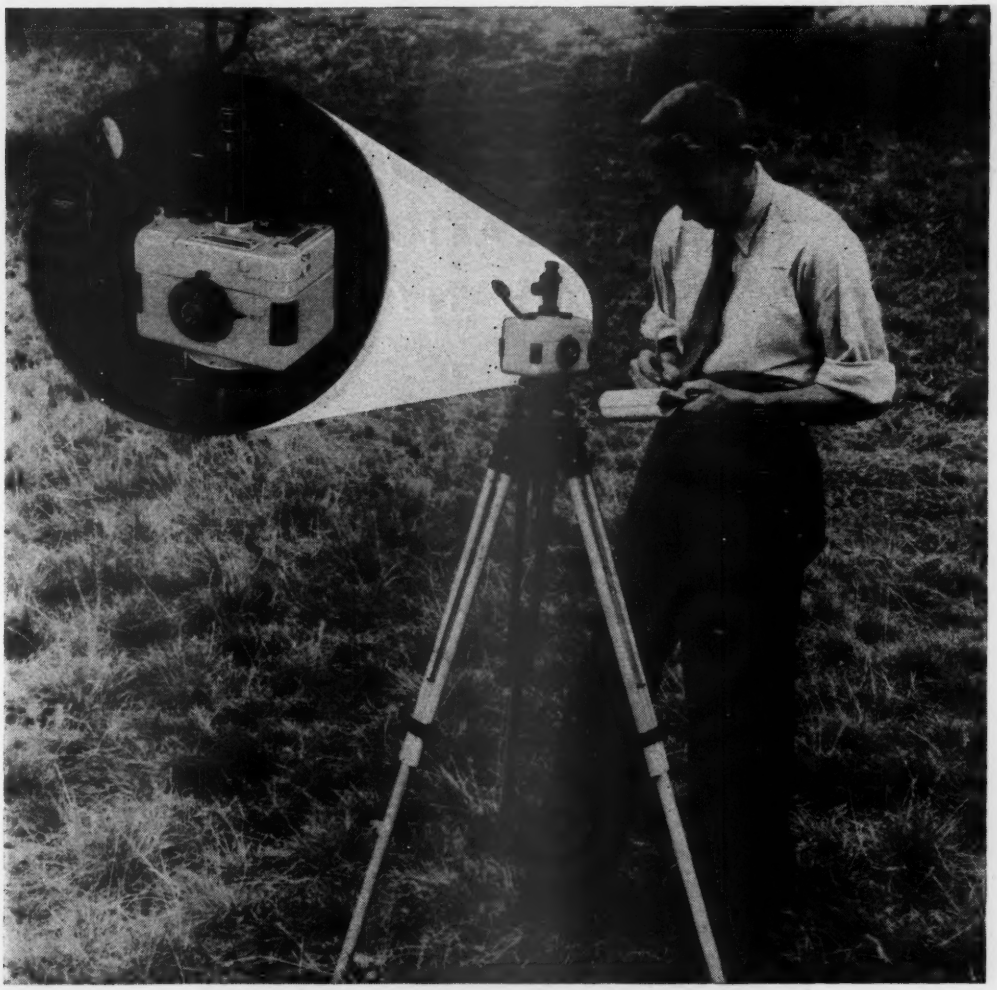

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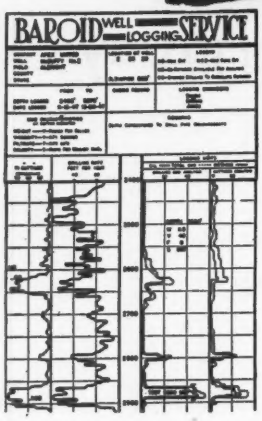

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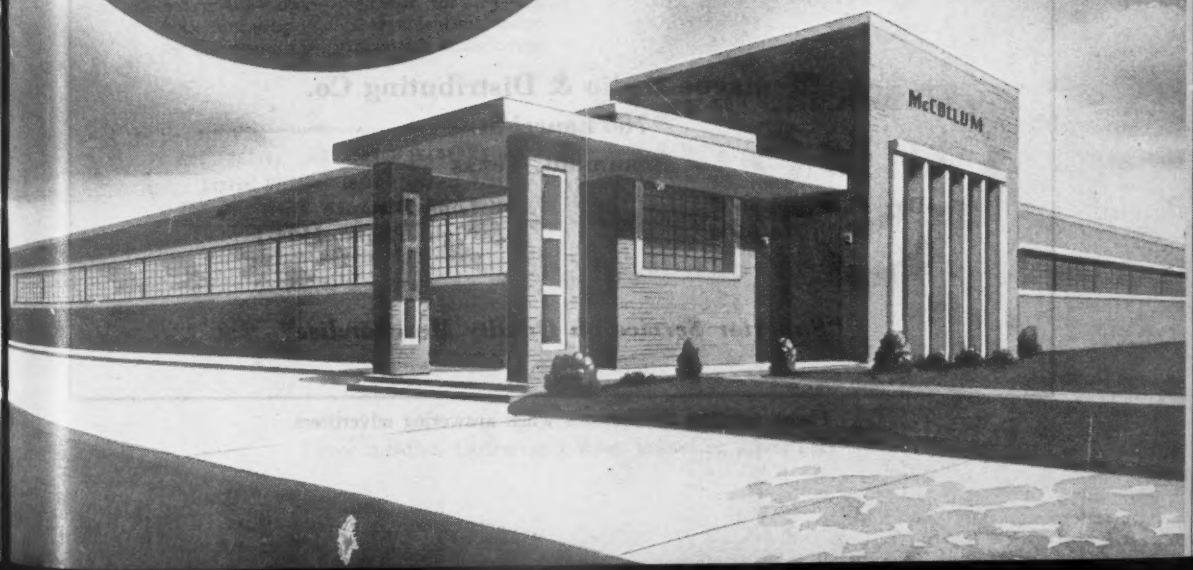

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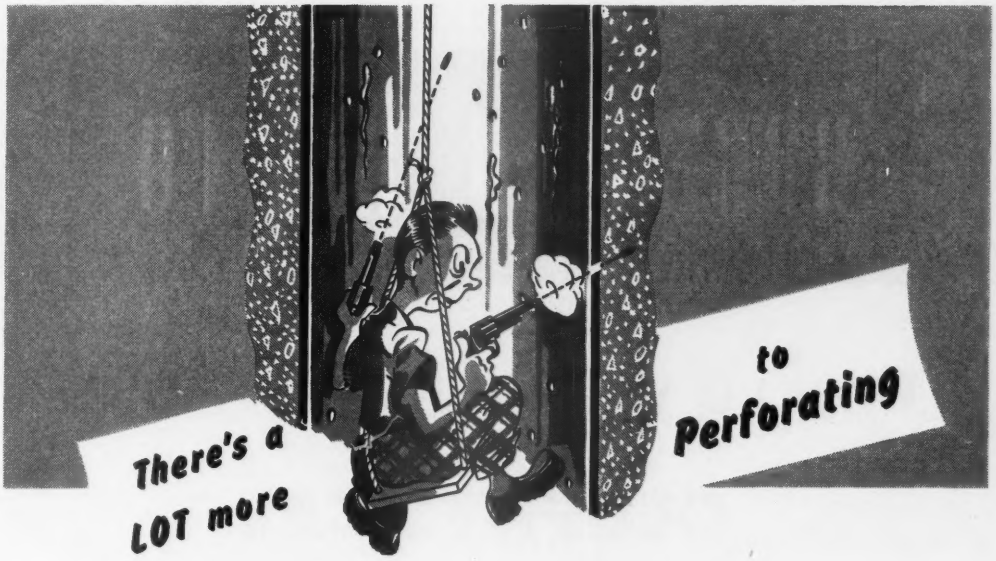

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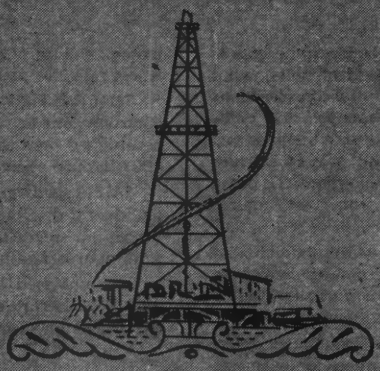

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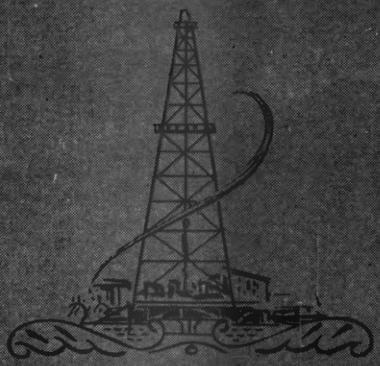

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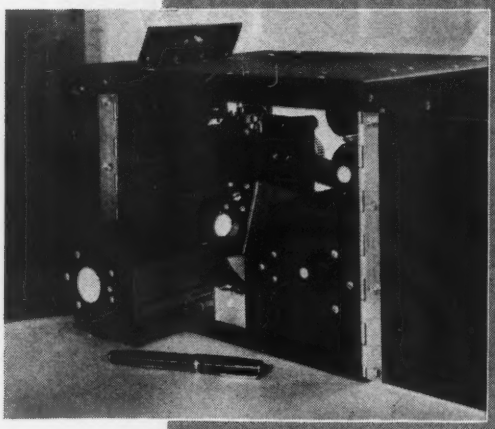

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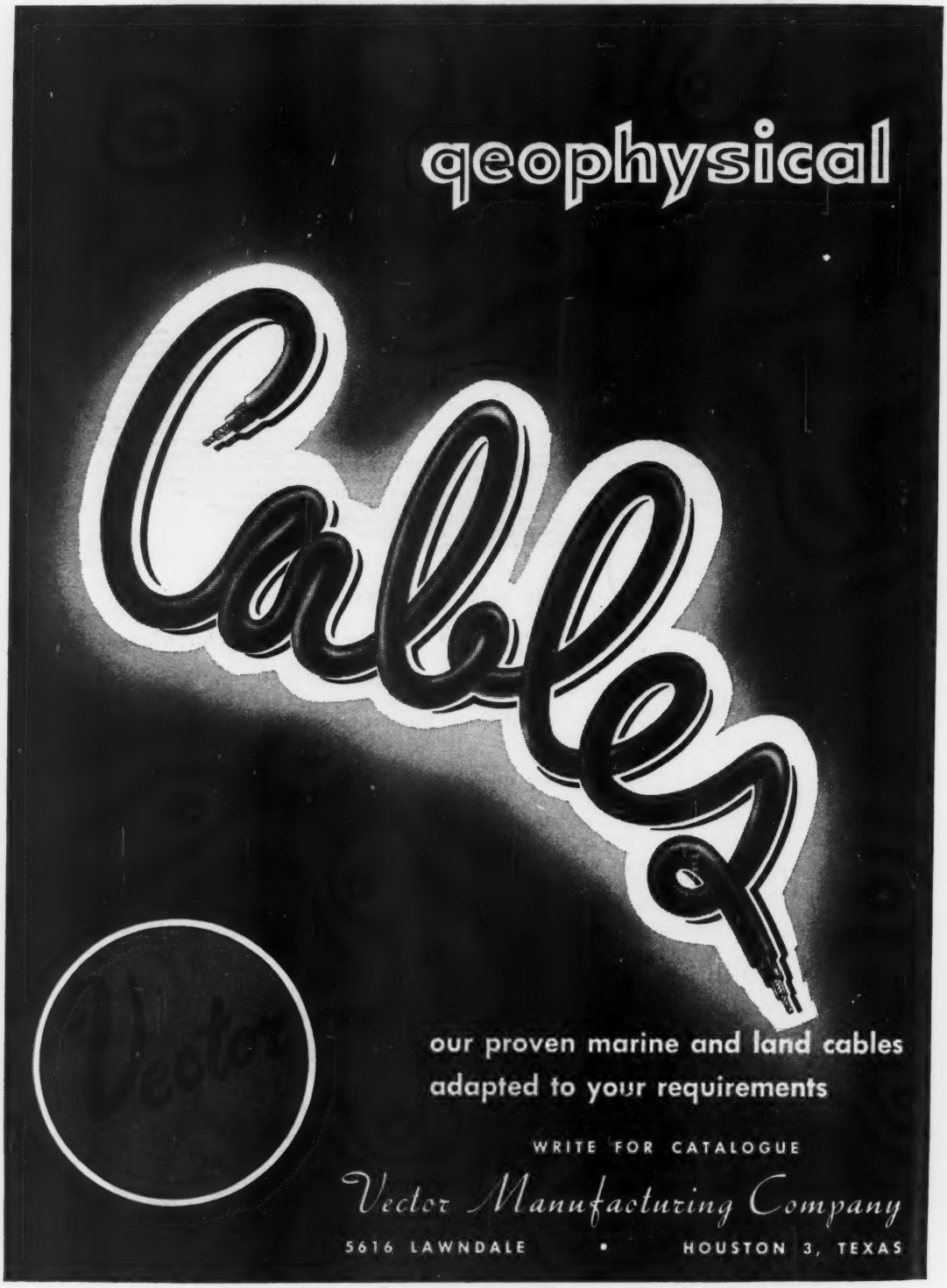
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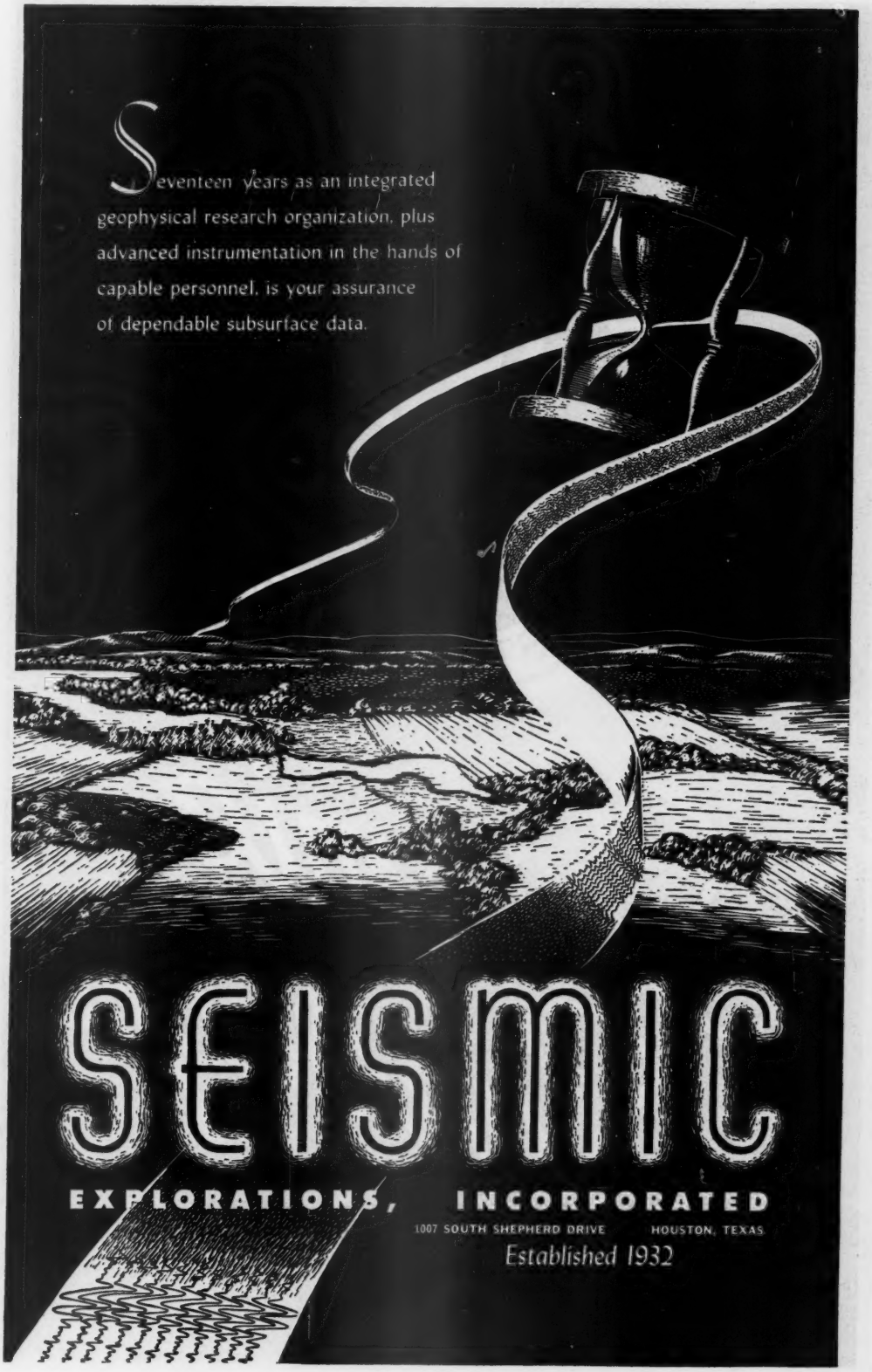
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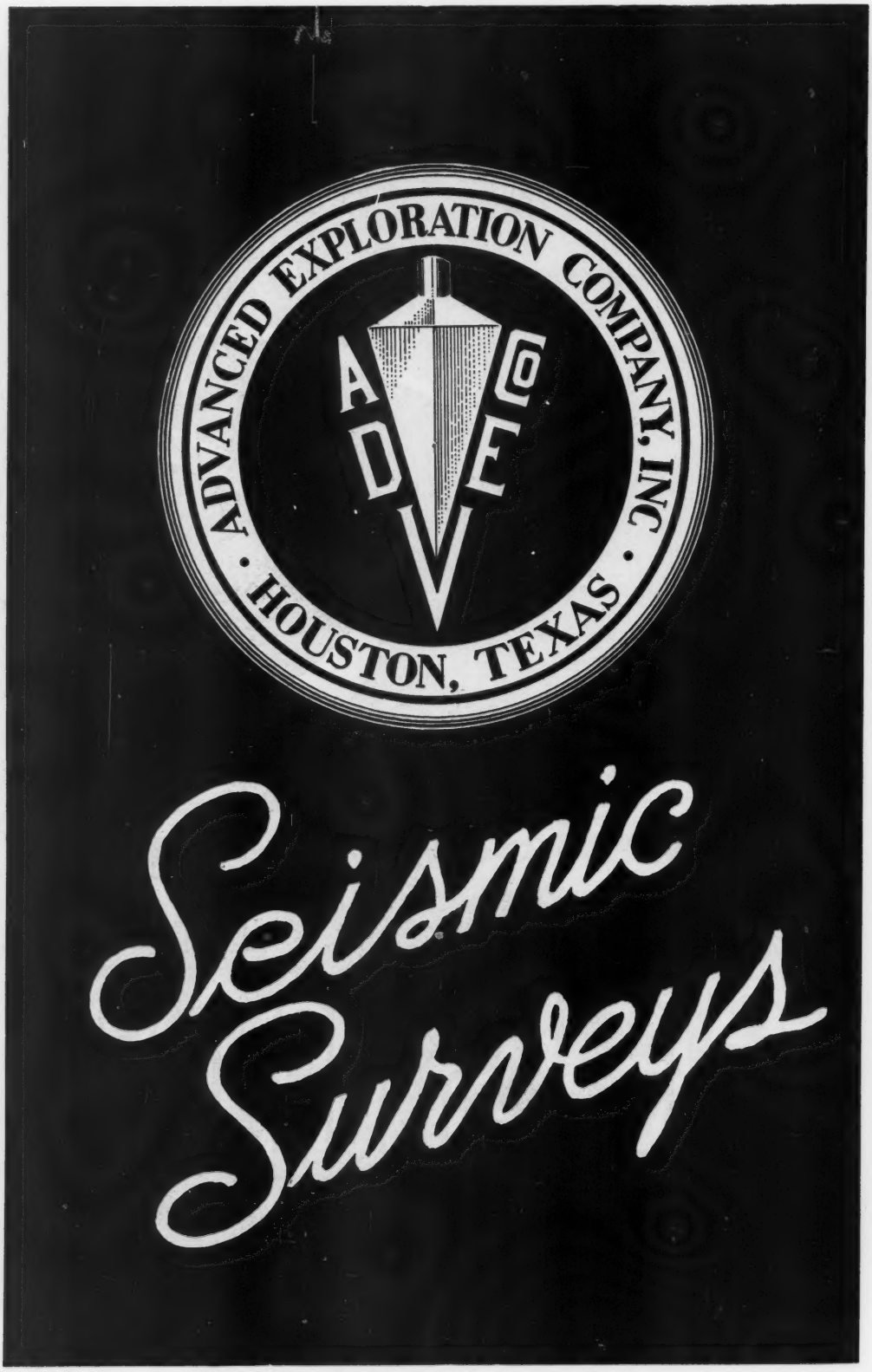
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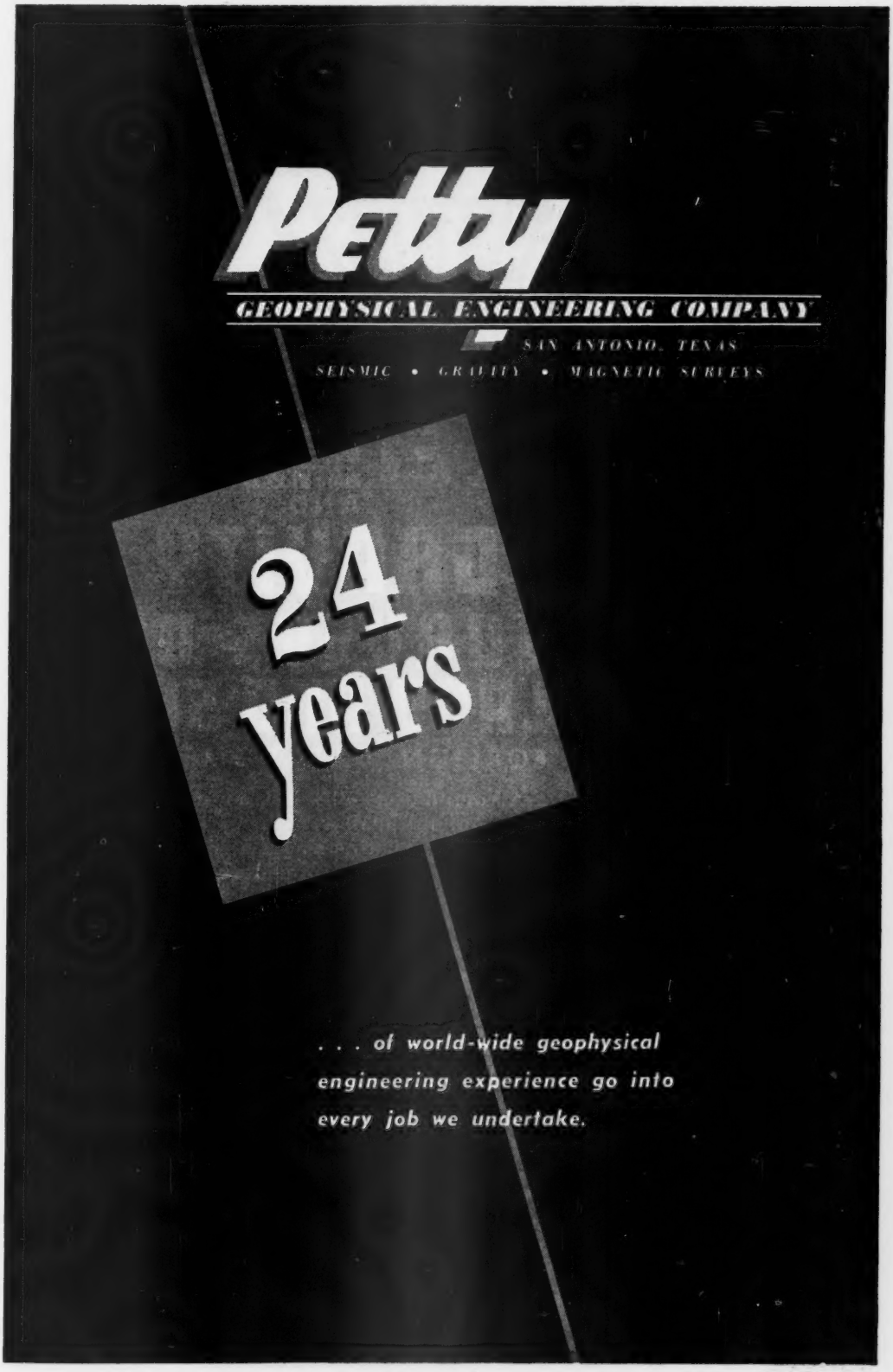
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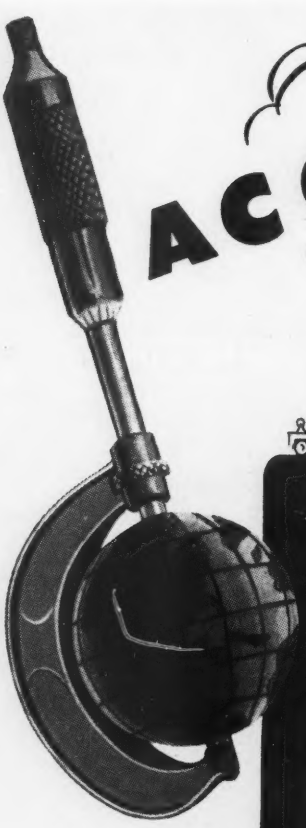

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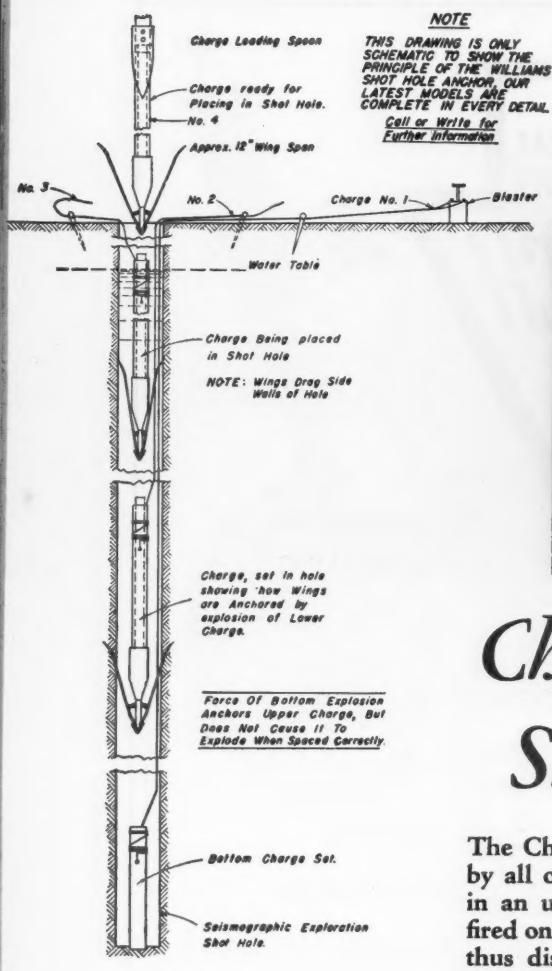
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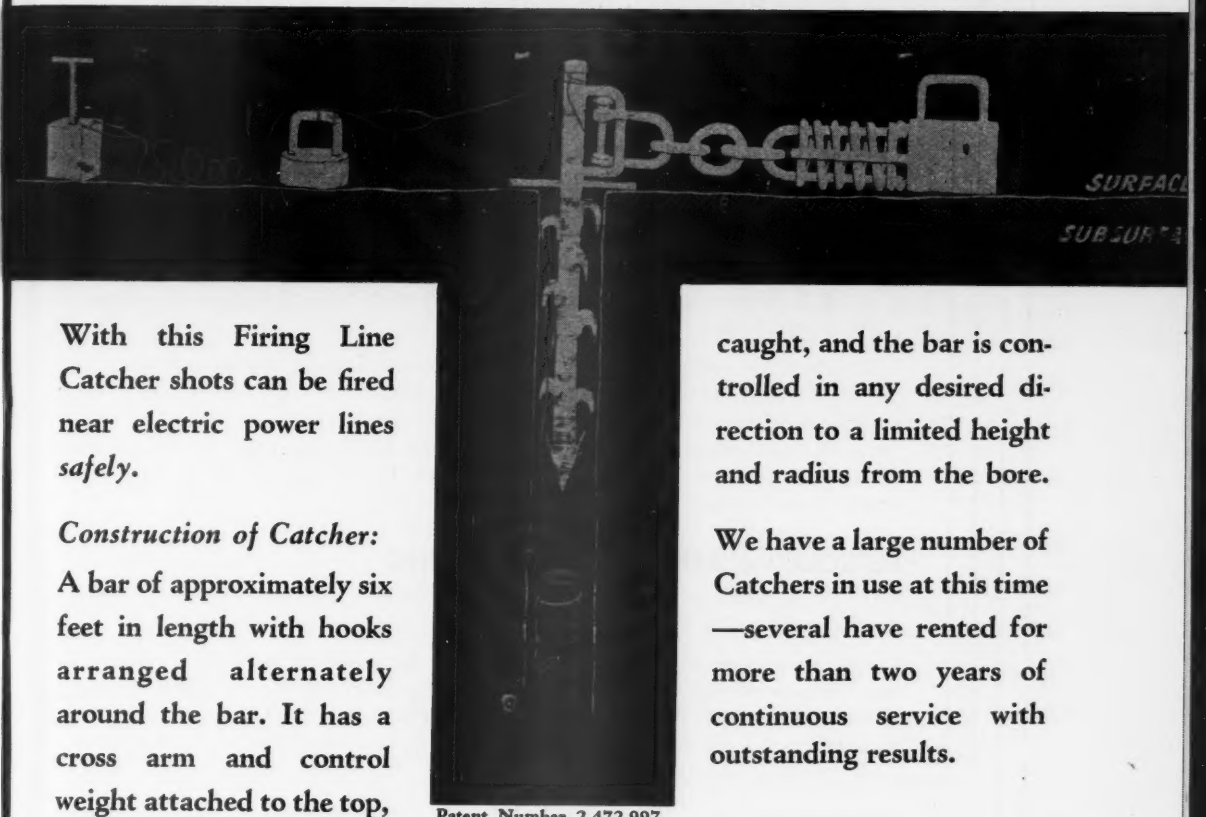

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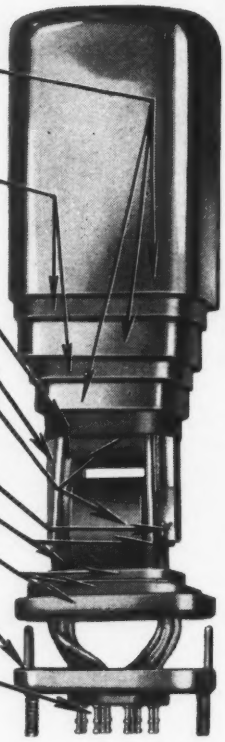
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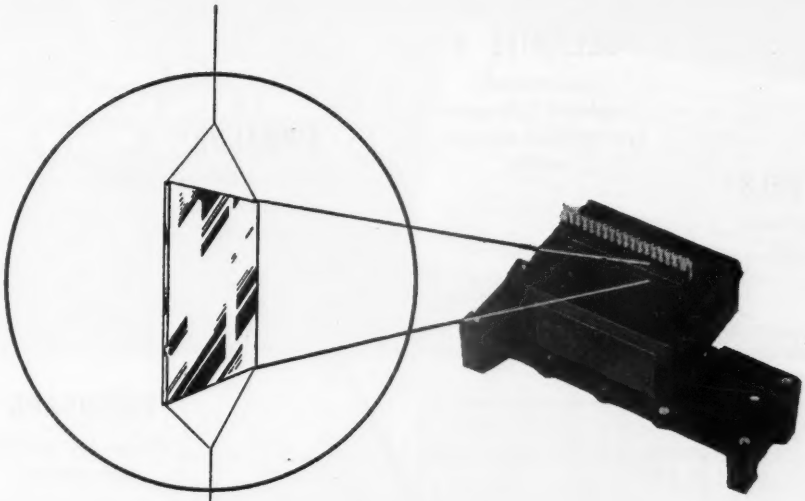

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LOG ANALYSIS

1) Water saturation S

R_o for the three sands under study is approximately 2 ohms in neighboring wells.
All three sands have an average true resistivity R_t = 7.5 ohms.

$$S = \sqrt{\frac{2}{7.5}} = 51.5\%$$

2) Formation water resistivity R_w

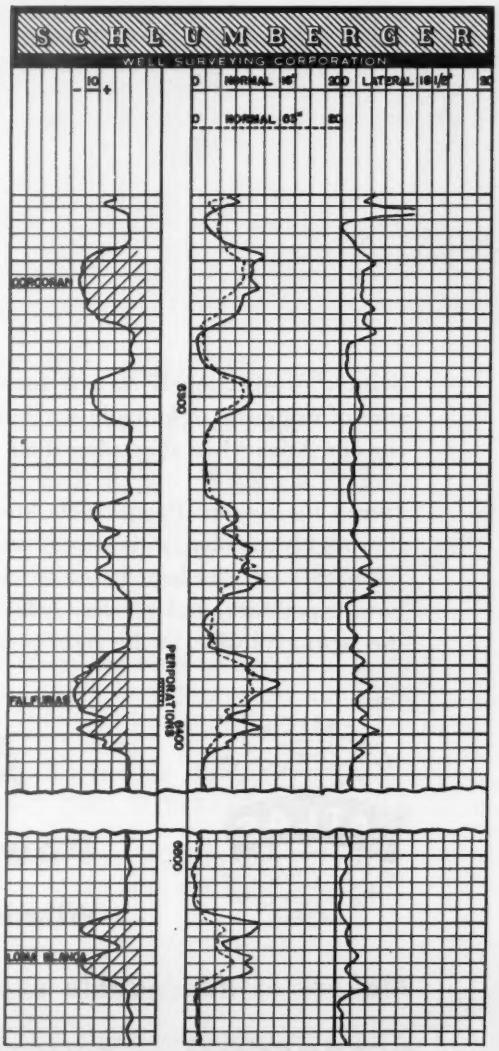
With $SP = -50^* \log_{10} \frac{R_m}{R_w} = -40$ mv.,

R_w = 0.16 approx. at BHT
*(Unclean sands demand lower coefficient)

3) Porosity p

$$F = \frac{R_o}{R_w} = \frac{2}{0.16} = 12.5 \text{ approx.}$$

$$p = \sqrt[m]{\frac{1}{F}} = 28\% \text{ for } m = 2$$



CORE ANALYSIS

Corcoran Sand	Porosity	29%
	Permeability	300 md.
	Residual Water	54%
Falfurrias Sand	Porosity	28.5%
	Permeability	110 md.
	Residual Water	41%
Loma Blanca Sand	Porosity	27%
	Permeability	96 md.
	Residual Water	44%

PRODUCTION RESULTS

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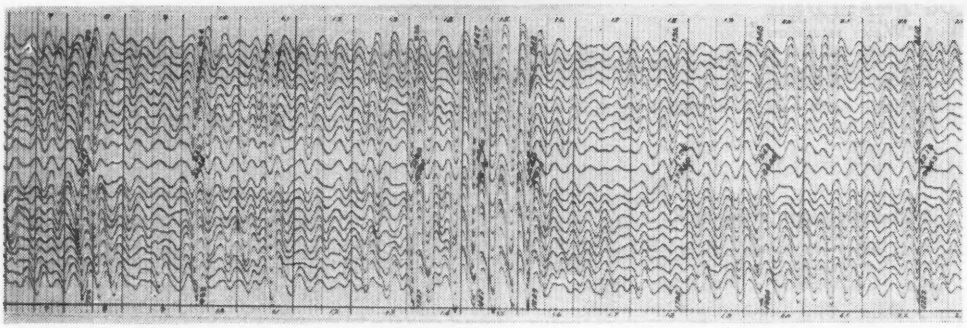

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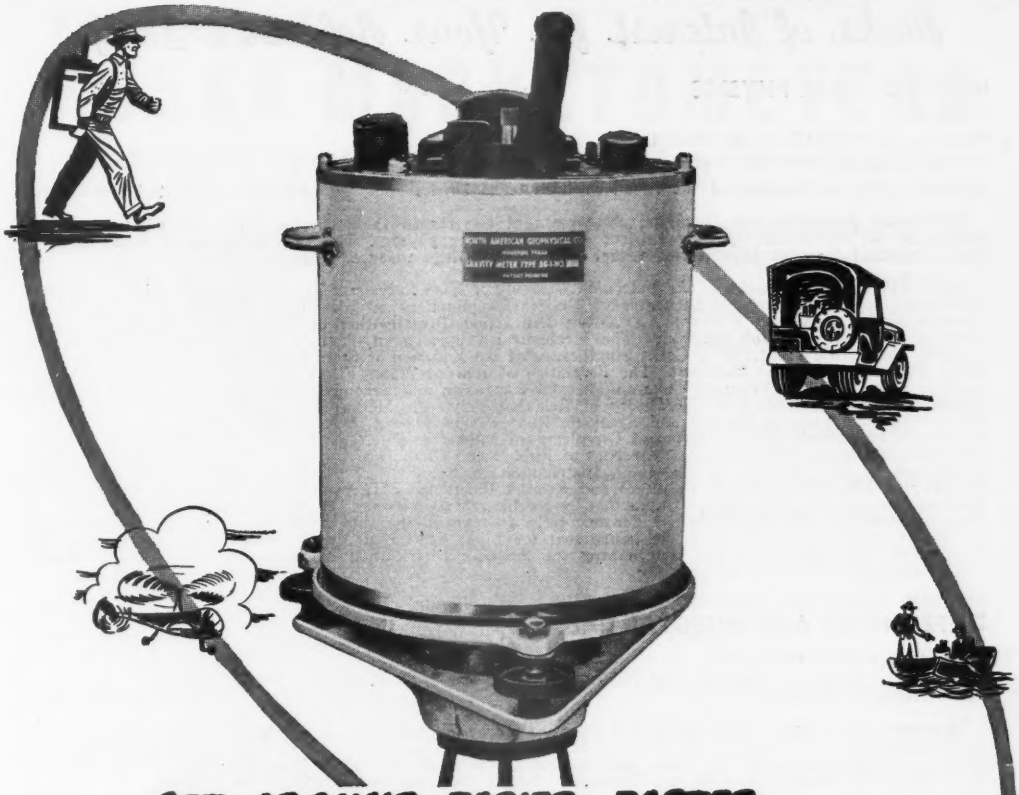

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Symposium

Edited by DR. HOWARD A. ROBINSON

Manager, Physical Research, Armstrong Cork Company

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Thirty-nine physicists and chemists, all prominent experts in their special fields, contributed to this symposium on the relatively new subject of high-polymer physics. The results discussed come largely from industrial research laboratories rather than from college research groups.

CONTENTS: *Determination of the Molecular Structure of High Polymers:* The Use of Color and Fluorescence Indicators for Determining the Structure of Glasses; Applications of Infra-Red Methods in the Structural Examination of Synthetic Rubber; An X-Ray Diffraction Investigation of Some Polygalacturonides. *The Physical Properties of High Polymers:* The Mechanical Properties of Textiles (The Simple Non-Newtonian Model); The Elastic Properties of Cork; Significance of the Equation of State for Rubber; Viscometric Investigation of Dimethylsiloxane Polymers; The Formation of Ionized Water Films on Dielectrics under Conditions of High Humidity; The Effect of Time on Thermal Expansion and Second—Order Transition Points in High Polymers; A New Approach to the Theory of Relaxing Polymeric Media; The Theory of Permanent Set at Elevated Temperatures in Natural and Synthetic Rubber Vulcanizates; Stress—Time—Temperature Relations in Polysulfide Rubbers; Crystallization of Unvulcanized Rubber at Different Temperatures; Tackiness of GR-S and Other Elastomers; Electrostatic Properties of Rubber and GR-S. *The Chemical Physics of High Polymers:* Application of the Methods of Molecular Distribution to Solutions of Large Molecules; Remarks on the Viscosity of Dilute Solutions of Polymers and Related Phenomena; Thermal Polymerization of Drying Oils; Determination of Polymer—Liquid Interaction by Swelling Measurements; Some Thermodynamic Properties of Slightly Cross-linked Styrene—Divinyl Benzene Gels. *Instrumentation and High Polymers:* Thermal Diffusion of Polymer Solutions; A Photoelectric Instrument for Light Scattering Measurements and a Differential Refractometer; An Attachment for Determining the Angular Distribution of Scattered Light in a 90-degree Turbidimeter.

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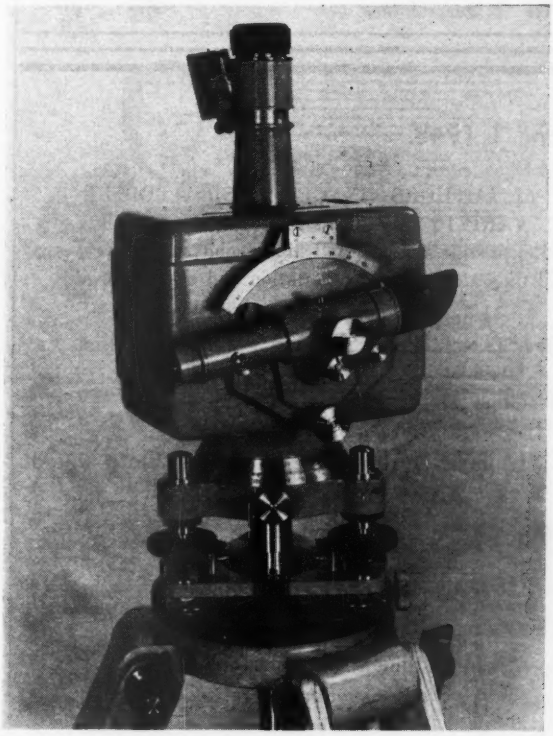

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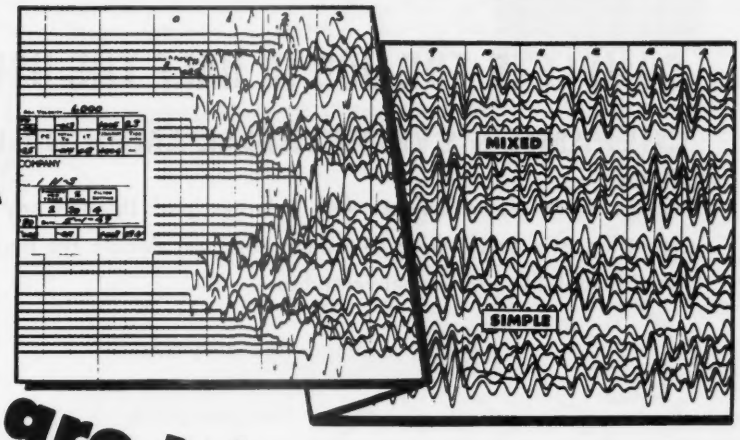

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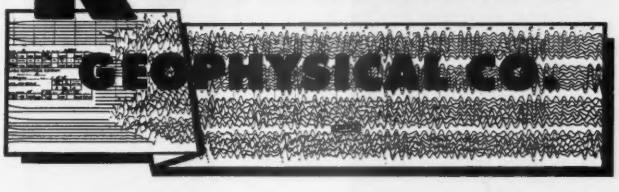

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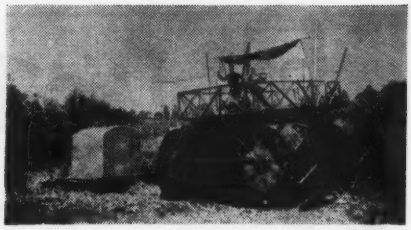

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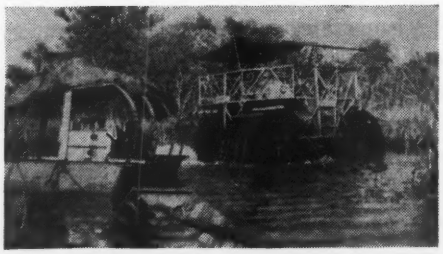

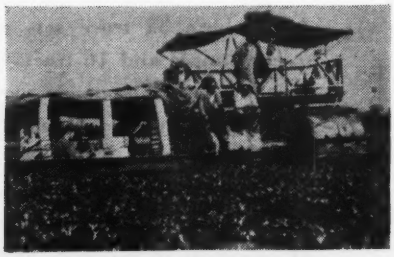

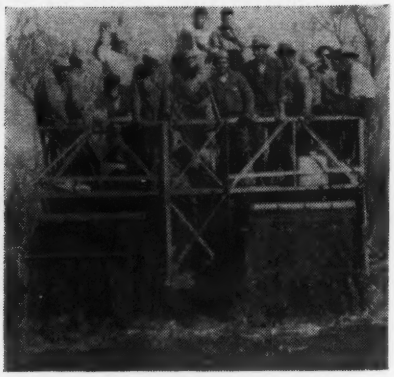

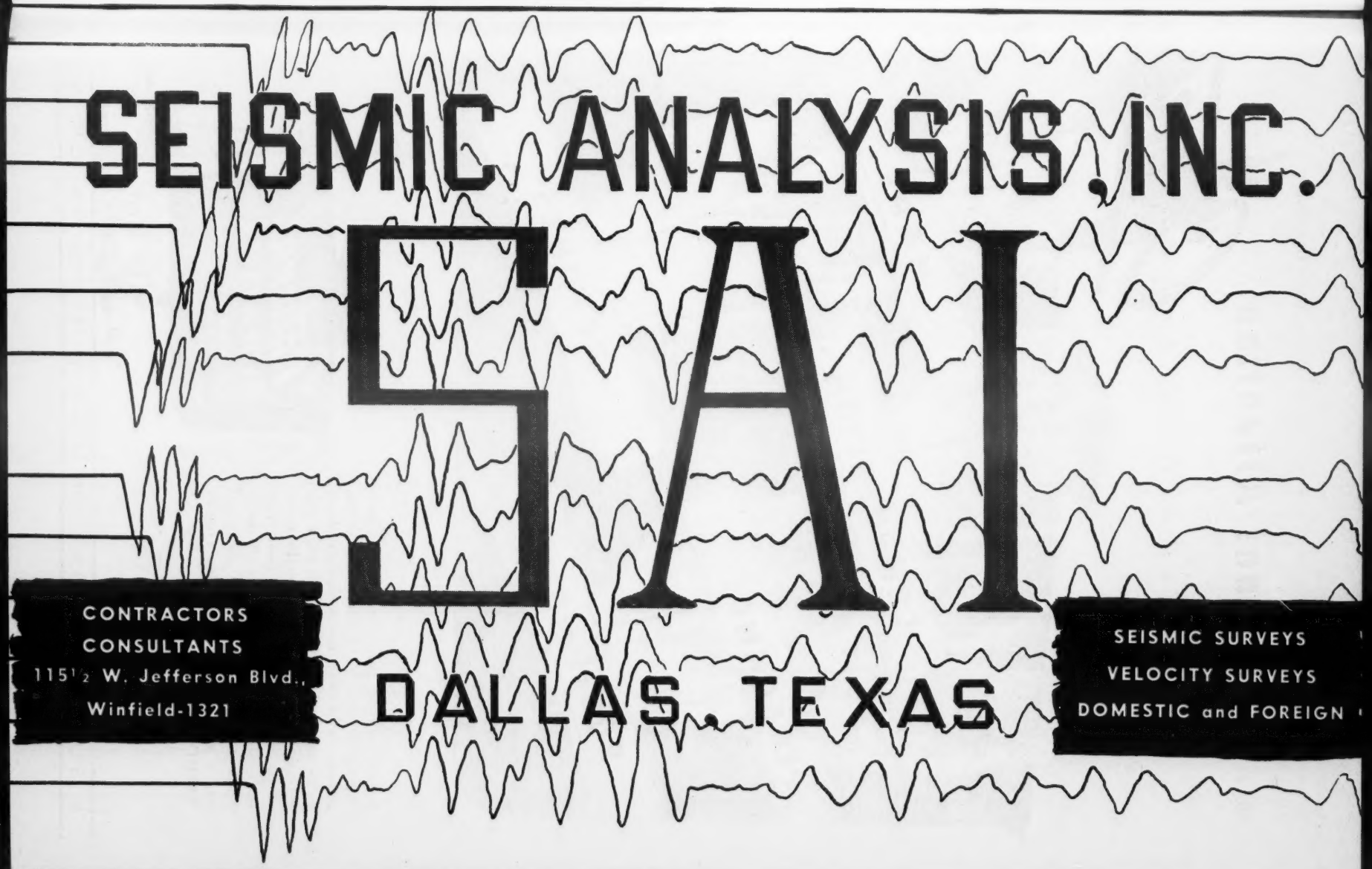
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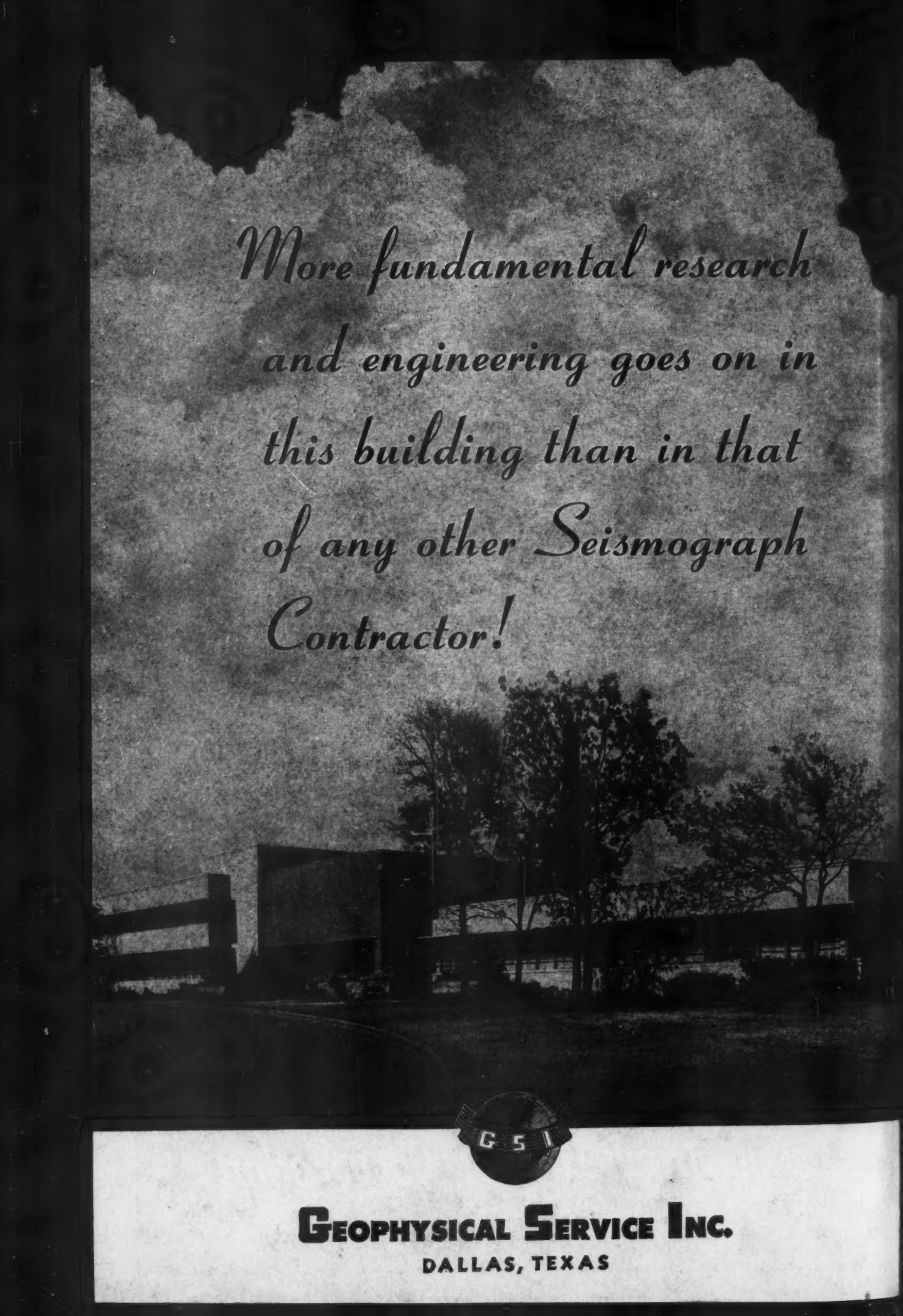

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